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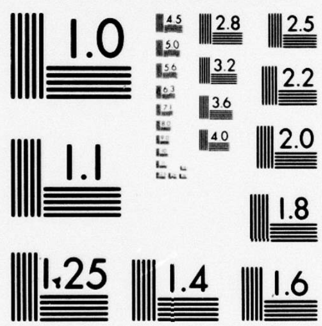

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Detailed field mapping in the Las Vegas Range, Sheep Range, Black Hills, and the Desert Range reveals the following geologic history: (1) Paleozoic miogeosynclinal sedimentation; (2) Sevier thrust faulting along the Gass Peak fault; (3) Tertiary low-angle denudation faulting; (4) Miocene sedimentation; (5) high-angle basin and range normal faulting; (6) landslides or further low-angle faults; and (7) oroclinal bedning at the extreme southern ends of the ranges in response to right lateral shear along the Las Vegas Valley shear zone.

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Geology of the Sheep Range, Clark County, Nevada

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Alexandria, VA 22332

Final report, 19 December 1979

A thesis submitted to the Massachusetts Institute of Technology, Cambridge, Massachusetts, in partial fulfillment for the degree of Doctor of Philosophy in Geology.

GEOLOGY OF THE SHEEP RANGE

CLARK COUNTY, NEVADA

by

PETER LORENTZ GUTH

B.S., U.S. Military Academy
(1975)

SUBMITTED IN PARTIAL FULFILLMENT
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DEGREE OF

DOCTOR OF PHILOSOPHY IN
GEOLOGY

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February 1980

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GEOLOGY OF THE SHEEP RANGE

CLARK COUNTY, NEVADA

by

PETER LORENTZ GUTH

Submitted to the Department of Earth and Planetary Sciences
on December 19, 1979 in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in
Geology

ABSTRACT

Detailed field mapping in the Las Vegas Range, Sheep Range, Black Hills, and a portion of the Desert Range reveals the following sequence of events:

(1) Miogeosynclinal sedimentation of latest Precambrian to at least Permian age. The sequence begins with a transgressive Eocambrian clastic wedge which is succeeded by carbonate bank sedimentation throughout the remainder of the Paleozoic. Periodic influxes of terrigenous material occurred during sedimentation. The sequence, 5900 m thick, is divided into 22 map units, from the Stirling Quartzite at the base to the Bird Spring Formation at the top. The preserved thickness of sedimentary rocks in the upper plate of the Gass Peak thrust in the Sheep Range is 4100 m, and the upper Mississippian Indian Springs Formation is the youngest formation present.

(2) Sevier thrusting along the Gass Peak thrust. The age and the horizontal displacement on the thrust fault remain poorly constrained. The Gass Peak thrust formed between Permian and Miocene time. Estimates for displacement range from 10-60 km, with a figure of 30 km most probable. The upper plate moved relatively eastward with a stratigraphic displacement of 5900 m. The base of the Gass Peak thrust forms a complex schuppen zone, and it does not follow a simple décollement behaviour within the sedimentary sequence. The thrust cuts down section to the west, and may be controlled in some way by the presence of the Eocambrian clastic wedge. Lower plate Paleozoic rocks may be present in the subsurface as far west as the Spotted Range 60 km from the outcrop of the thrust ramp in the Las Vegas Range.

(3) Low-angle denudation faulting of probable Tertiary age. Low-angle faults present near the crest of the Sheep Range place younger rocks on older rocks, whereas low-angle faults in the Hoodoo Hills Havoc place older rocks on younger rocks. The fault blocks moved down gentle slopes toward the west. Intensively brecciated hanging wall rocks indicate deformation at shallow crustal levels. Low-angle faulting may be present in large areas north of Las Vegas Valley and west of the Sheep Range.

(4) Miocene (?) deposition of the Horse Spring Formation conglomerate and tuff.

(5) Landsliding or additional low-angle faulting.

(6) High-angle faulting. High-angle faults trend north-south, downdrop rocks on their western sides, and caused rotation of rocks in the Sheep Range. Most of the rotation within the Sheep Range takes place on the easternmost fault, the Mormon Pass fault. High-angle faults can account for 15% extension within the Sheep Range.

(7) Right-lateral drag along the Las Vegas Valley shear zone. Rotation is limited to the extreme southern ends of the ranges.

Work in the Sheep Range suggests that the Las Vegas Valley shear zone forms an intracontinental transform fault separating zones undergoing differential Tertiary extension. The Spring Mountains south of the shear zone have undergone relatively minor extension during the Tertiary, whereas the ranges and valleys north of the shear zone have undergone extreme extension. Extension has not been uniform, and appears to be concentrated in the region between the west side of the Sheep Range and the Specter Range. This region, now 90 km wide, may have extended 100% during the late Tertiary.

The Las Vegas Valley shear zone and the Lake Mead fault system may have acted together on a broader scale to control extension between the Colorado Plateau and the vicinity of the Specter Range. Strike-slip faults separate areas that have undergone extreme extension from areas of minor extension.

Thesis Supervisor: Dr. B. C. Burchfiel
Title: Professor of Geology

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For financial support of my graduate studies, I thank the Fannie

and John Hertz Foundation and the U.S. Army, Corps of Engineers. For financial support of field work I thank the Department of Earth and Planetary Sciences, M.I.T., Geological Society of America Penrose grants 2335-78 and 2456-79, U.S.G.S., and N.S.F. Grant EAR 77-13637.

I would like to dedicate this thesis, and the three years of my life that it represents, to three denizens of the Cordillera. Two sparked my initial interest in geology ten years ago, _Helicoplacus_ and _Olenellus_. The third brought a sense of grandeur, majesty, and excitement to the three summers I spent in Nevada, _Ovis canadensis nelsoni_. Field geology offers the chance to approach nature, and marvel at the intricacies of life in an evolving world. For reminding me of this, I thank my two little Cambrian critters and my bighorn sheep.

Geologic Map. Blackline copies of the geologic map, cross sections, and stratigraphic column are available at cost from the author (try GSA membership directory for current address). The map and sections are available at a scale of 1:50,000 as included in the thesis, and at the scale of 1:24,000 at which they were drafted. The 1:24,000 map does not have topography.

CHAPTER I. INTRODUCTION

Purpose

Mapping in the Sheep Range, the Black Hills and parts of the Las Vegas and Desert Ranges was undertaken to provide information on:

1) Paleozoic and upper Precambrian miogeosynclinal sedimentation and paleogeography;

2) Mesozoic thrust faulting;

3) Cenozoic low-angle faulting;

4) Cenozoic strike-slip faulting; and

5) Cenozoic Basin and Range high-angle faulting.

The mapped area is located about 40 km north of Las Vegas, Nevada and includes parts of four mo in ranges (Figure 1); from east to west they are the Las Vegas Range, the Sheep Range, the Black Hills (also known as the Corn Creek Range), and the eastern part of the Desert Range. This area formed part of the Cordilleran miogeosyncline throughout the late Precambrian and Paleozoic and received sediments during each of the Paleozoic periods. During the late Mesozoic Sevier orogeny, most of the rocks in the map area moved relatively eastward on the Gass Peak thrust. Cenozoic deformation consisted, from oldest to youngest,

Figure 1. Regional setting of the Study Area.

Location of the study area and of adjacent mountain ranges. Many of the ranges merge topographically, making separation difficult, particularly the Desert Range, East Desert Range, Sheep Range, and Las Vegas Range. The mapped area is shown by a stippled pattern which is also the area shown on the geologic map, Plate I. Three of the thrust faults from the Sevier belt are indicated.

Abbreviations used: FR, Fossil Ridge; GP, Gass Peak; HP, Hayford Peak; QM, Quartzite Mountain; SP, Sheep Peak; and WS, Wamp Spring.

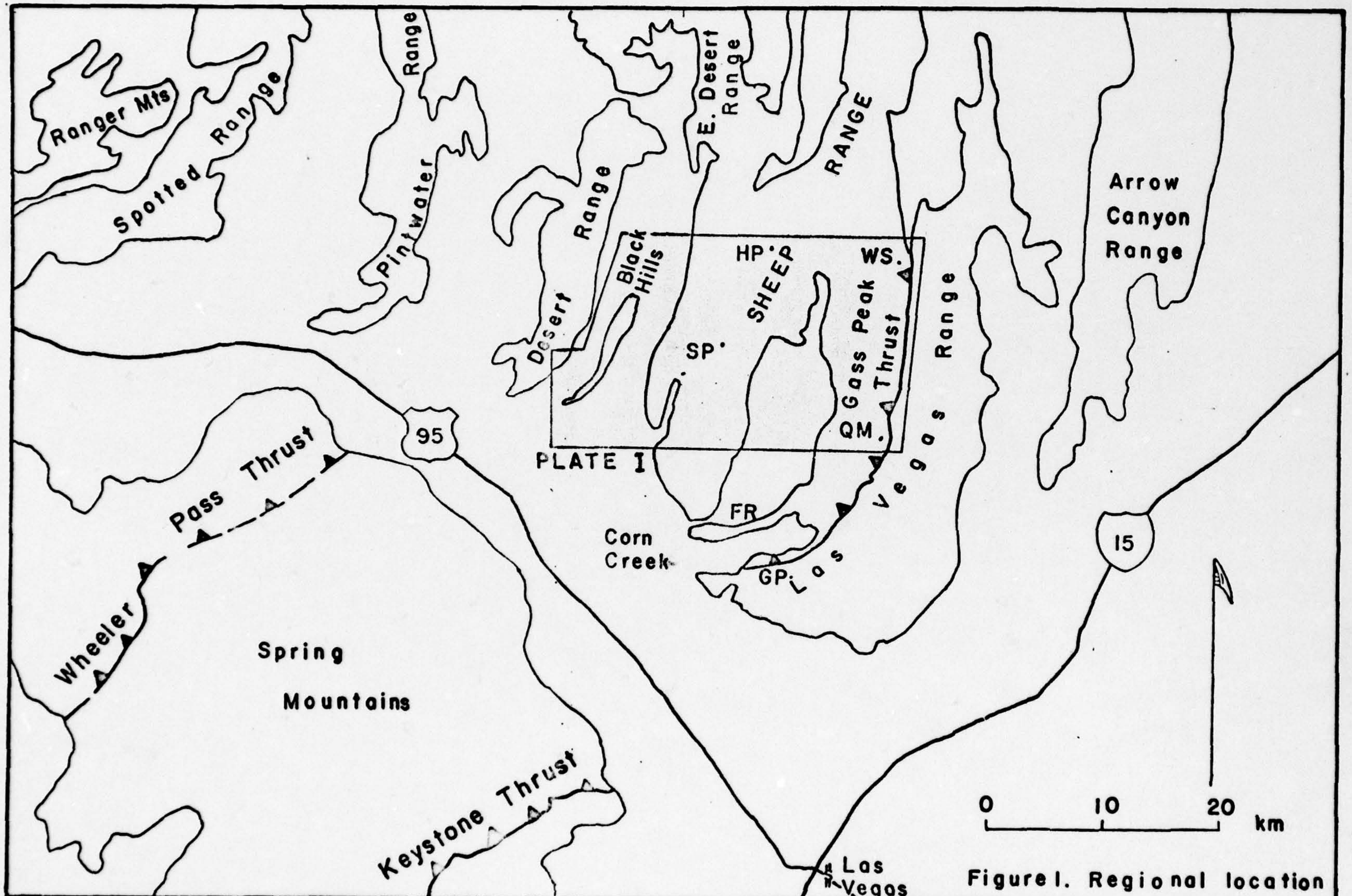


Figure 1. Regional location

of low-angle, near-surface extensional faults; right-lateral shear along the Las Vegas Valley shear zone; and high-angle Basin and Range faulting. This Cenozoic history accounts for the current topographic expression of the region.

The geologic history of the Sheep Range area has an importance beyond its immediate area of southern Nevada. The Sheep Range is the first area north of the Las Vegas Valley shear zone to be mapped in detail. It provides information and constraints on the extent and mechanics of Mesozoic compression in the Cordilleran thrust belt and of Cenozoic extension in the Great Basin. Mapping in the Sheep Range contributes to our understanding of orogeny in western North America.

Location and Extent of the Area

Figure 1 shows the location of the area mapped, and indicates the boundaries of the geologic map (Plate I). The area is bounded on the south by 36°30' north latitude. The eastern boundary runs just below the crest of the Las Vegas Range, at about 115°03' west longitude. The northern boundary runs from north of Wamp Spring and Mormon Well in the Las Vegas Range, to the north of Hayford Peak, and on the south side of Pine Canyon. This approximately follows

36°38' north latitude. The western boundary is in the alluvium between the Black Hills and the Desert Range. A small segment of the Desert Range was mapped to define the Cenozoic fault pattern.

Figure 2 shows the location of places mentioned in the text. U.S. Highway 95 north from Las Vegas provides access to the area. Approximately 37 km from Las Vegas, a well maintained gravel road leads to Corn Creek. From Corn Creek the Mormon Well Road provides access to the east side of the Sheep Range and the Las Vegas Range. Side roads provide access to Wamp Spring and to the Pine Nut Camp trails. Alternatively, from Corn Creek the Alamo Road provides access to the west side of the Sheep Range, the Black Hills, and the east side of the Desert Range. Side roads lead to the foot of the range at Joe May Canyon, Cow Camp, and Deadman Canyon/Hidden Forest. Both the Mormon Well and Alamo Roads require vehicles with high clearance, although not four wheel drive. The entire area lies within the Desert National Wildlife Range. The Fish and Wildlife Service manages the area as wilderness pending formal designation as an official wilderness to protect bighorn sheep herds and habitats. They have blocked many of the roads shown on the topographic maps, usually at the base of the range. Camping within the Wildlife Range has strict limitations, and the few springs are not available for human

Figure 2. Locality Index.

This map indicates the approximate position of all place names within the map area that are referred to in the text. All of these locations also appear on the topographic base map, but may be difficult to locate on plate 1.

use. The Desert Range and points farther west have the additional restriction of being within the U.S. Air Force Nellis Bombing and Gunnery Range. All points within the mapped area can be reached by foot from the trail heads, but most of the crest of the Sheep Range requires long, strenuous hiking.

Physiography

Elevations in the region mapped range from about 3500 feet (1067 m) in the valley between the Desert Range and the Black Hills, to 9912 feet (3021 m) atop Hayford Peak. Las Vegas Range elevations vary from 5000 feet to 7133 at Quartzite Mountain, although much lower elevations occur outside the mapped portion of the range. Elevations in the Sheep Range vary from 5000 feet to 9912 feet; along most of the range the local difference in elevation averages about 4000 feet from the base to the crest of the range. The Black Hills rise a maximum of about 1100 feet from the alluvium, with elevations between 3500 feet and 5454 feet. Only a small portion of the Desert Range was included in the mapped area: elevations there range from 3600 feet to 4492 feet.

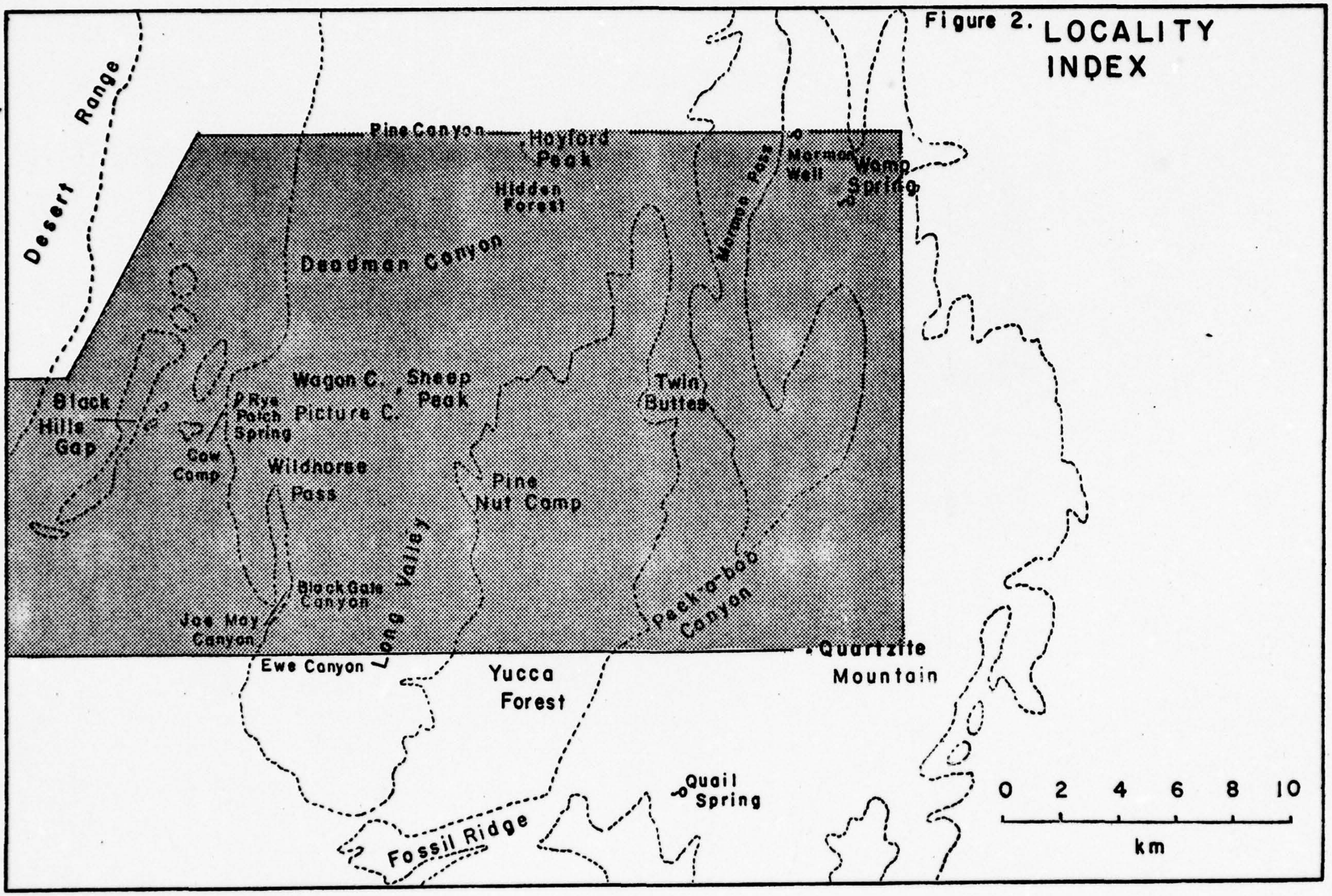


Figure 2. LOCALITY INDEX

Vegetation

Annual precipitation in the Sheep Range varies with elevation, from under 10 cm in the valleys to over 38 cm atop the peaks (Fish and Wildlife Service, 1974). Vegetation adapted to increased precipitation and decreased temperature with rising elevation leads to recognition of five plant communities in the ranges: creosote below 5000 feet, blackbrush-yucca between 5000 and 6000 feet, pinon pine-juniper above about 6000 feet, ponderosa pine-white fir above 7000 feet, and bristlecone pine-limber pine at the highest elevations in the Sheep Range (McQuivey, 1976). In addition to other controls, there is bedrock control on the trees. Ponderosa pines prefer quarzite to dolomite (the Eureka Quartzite to either the Springs or the Laketown Dolomite). East of Sheep Peak several faults can be picked out by the contrast in vegetation: ponderosas on the Eureka, and pinons and junipers on adjacent dolomite bedrock in an otherwise identical setting of exposure, elevation, and slope.

The Black Hills and the Desert Range have no trees, very little vegetation, and optimal outcrops of bedrock. Within the Sheep Range and the Las Vegas Range, vegetation often becomes a significant factor in mapping the geology. Ponderosa pines particularly tend to obscure contacts and

outcrop, as they prefer gentle slopes with greater soil cover.

Note on Units

With the exception of elevations which are given in feet, all units employed in this thesis belong to the SI system. This exception provides better agreement between the text and the geologic map, which has a topographic base with elevations and contours in feet.

Stratigraphic unit thicknesses are given in meters. Almost without fail the older original publications list thicknesses only in feet. Values have been converted and rounded to the nearest meter. This precision is unwarranted in many cases, since the precision of the original published data is typically not stated.

Methods

The area includes all of two 7.5' (1:24,000) quadrangles, the Black Hills and Hayford Peak Southwest, and parts of five others: Hayford Peak Northwest, Northeast, Southeast; White Sage Gap, and the Black Hills Southwest (see Figure 3). The Hayford Peak quadrangle was published only at 1:62,500 in 1960, but was surveyed at 1:24,000 and

Figure 3. Quadrangle Index.

All quadrangles in the immediate vicinity of the map area are indicated on this figure. The Hayford Peak 7.5' quadrangle maps are available from the U.S.G.S. only as preliminary "T" sheets, and the map was published only as a 15' quadrangle. The "T" sheets were used to construct the topographic base of plate 1, and proved to be extremely *reliable for field mapping.*

The 15' quadrangles have 80 foot contour intervals and are published at 1:62,500, whereas the 7.5' quadrangles have 40 foot)or even 20 foot) contour intervals and are published at 1:24,000.

preliminary "T" sheets are available from the U.S. Geological Survey and were used for the topographic base. All have 40 foot contours, except for the Black Hills Southwest which has 20 foot contours. On the topographic base, this area was redrafted with 100 foot contours.

In the summer óf 1977, mapping in the Las Vegas Range was done on the Hayford Peak 15' quadrangle enlarged to a scale of about 1:30,000. The remaining two summers mapping was done exclusively on the 1:24,000 sheets. In 1978 mapping covered the east side of the Sheep Range and in 1979 the west side of the Sheep Range, the Black Hills, and the Desert Range.

In addition to the topographic maps, I had aerial photographs covering the entire area. At lower elevations as in the Desert Range or the Black Hills, the photographs clearly reveal the geology. But at elevations above about 6000 feet the increased vegetation renders the photographs much less useful. Contacts cannot be readily discriminated on the photographs, although the photographs still help to locate positions and interpret relations.

Stratigraphic sections were not measured in the course of this study. The thickness of thinner units was visually estimated. The thickness of other units was calculated from the map pattern of outcrops, averaging the thickness from several exposures. Unless specifically credited to

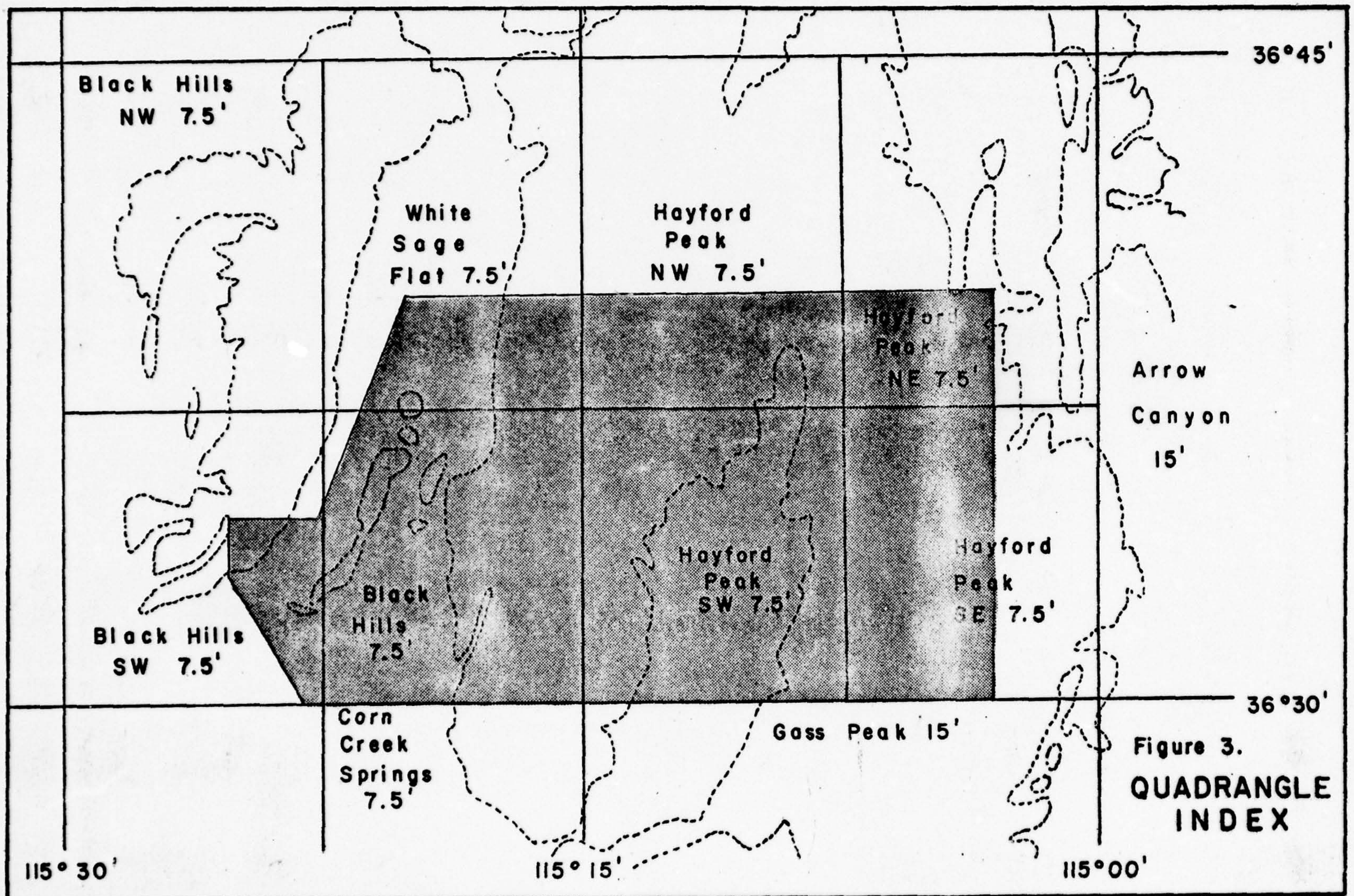


Figure 3.
QUADRANGLE INDEX

another geologist, all thicknesses represent the author's estimate based on geologic mapping. The Sheep Range offers a number of potential studies of Paleozoic stratigraphy and depositional environments, which were beyond the scope of this study.

Previous Work

In 1871 during its first field season the Wheeler Survey dispatched a party into the area. "A small topographical party, in charge of F.R. Simonton, will proceed via Las Vegas Ranch to Mormon Wells, or Sheep Mountain Springs, north and east from Gass Peak, and Vegas Range..." (Wheeler, 1872, p. 65). Apparently neither of the survey's geologists visited the area, and the published reports of the Wheeler Survey make no mention of the geology of the area. Atlas sheet 66 provided the first topographical (hachure) map including the region, although the arrangement of the mountains is highly inaccurate.

Spurr (1903) published the first geologic map covering the region, and noted the difficulty in using the Wheeler Survey base map. Spurr's usage of mountain range names does not correspond with current usage. His comments on the geology of the Sheep Range area were based largely on the work of R.B. Rowe, who died before he could publish

his work. Spurr and Rowe recognized Cambrian, Ordovidian, Devonian, and Carboniferous rocks in the Las Vegas and Sheep Ranges. They interpreted the structure largely in terms of folds, and recognized several large faults. Spurr's U.S.G.S. Bulletin 208 provided a quick reconnaissance into the area and aided in the construction of a geologic map of the United States.

In the 1920's C.R. Longwell started work in southern Nevada. As a result of his work the major elements of the regional geology appeared in a series of publications. Longwell (1926) named the Gass Peak thrust in a paper covering the entire thrust belt of southern Nevada. In 1930 he published a paper on faulted fans west of the Sheep Range in Sheep Basin, north of the map area. In two publications (1933, 1945) Longwell described low-angle normal faults in the Desert Range. He proposed the Las Vegas shear zone as a major zone of right lateral faulting (1960). Longwell's reconnaissance mapping culminated in a report on the geology of Clark County with a geologic map at a scale of 1:250,000 (Longwell and others, 1965). His observations in adjacent areas outside Clark County form much of the basis for discussions of Lincoln County to the north (Tschanz and Pampeyan, 1970).

More detailed work has been done in a number of ranges surrounding the Sheep Range. The Spring Mountains with

their exposures of the thrust belt have been mapped by a number of workers and compiled on a single base map (Burchfiel and others, 1974). To the west, Burchfiel (1964, 1965) mapped the Specter Range, and the detailed work of the U.S. G.S. geologists in the Nevada Test Site produced a number of geologic maps. To the immediate west of the Sheep Range, little mapping has been done in the Desert Range, Pintwater Range, and the Spotted Range. One exception consists of paleomagnetic work in the Eocambrian section in the Desert Range (Gillette and Van Alstine, 1979; Van Alstine and Gillette, 1979); that section has also been measured (Stewart, 1970).

North of the Sheep Range Reso (1963) published a stratigraphic section for the Pahranagat Range, but no map was published. To the east of the Las Vegas Range, Langenheim and others (1962) described the stratigraphy of the Arrow Canyon Range. Since that time numerous papers have added details to the stratigraphy, paleontology, and depositional environments of the Arrow Canyon Range, but only one abstract (Langenheim and Mahlburg, 1973) dealt with the structure, and the range has not been mapped.

Directly south of the map area, Ebanks (1965) mapped the Las Vegas Range in the Gass Peak Quadrangle. This work represents a continuation of his mapping.

A number of workers measured stratigraphic sections in the Sheep and Las Vegas Ranges. They include Eocambrian rocks (Stewart, 1970), Carrara Formation (Halley, 1974), Ordovician rocks (Ross, 1964), Sevy Dolomite (Osmond, 1962), Mississippian rocks (Webster, 1969), and Pennsylvanian-Permian rocks (Welsh, 1959).

CHAPTER II. STRATIGRAPHY

The miogeosynclinal sequence (see Plate III) in the Sheep Range can be divided into a basal clastic portion and an upper carbonate portion. The basal clastic section, here called the Eocambrian clastic wedge, consists of terrigenous units with a maximum thickness of 525 m. The Eocambrian clastic wedge ranges in age from upper Precambrian to Middle Cambrian. The upper carbonate part of the miogeosynclinal sequence can be divided into five packages. Thin terrigenous units occur throughout the section. The upper part of the Cambrian and the lower Ordovician contains 2110 m of dolomite with significant limestone and numerous influxes of silty material. The 50 m thick Eureka Quartzite forms the second package in the carbonate portion of the section. The next package consists of 685 m of dolomitic rocks representing the upper

Ordovician, Silurian, and the lower part of the Devonian.

Upper Devonian and Mississipian limestones form the fourth package about 735 m thick and containing significant clastic input. Uppermost Mississippian rocks represent the youngest geosynclinal sediments preserved in the Sheep Range but the fifth package forms the bulk of the Las Vegas Range beneath the Gass Peak thrust, where Pennsylvanian and Permian limestones reach a thickness of 1780 m.

No unconformities were noted in the Sheep Range Section. Comparison with better dated sections suggests that periods of erosion or non-deposition must have occurred. These hiatuses produced no clear angular unconformities, and only detailed stratigraphic work will be able to document them.

Nomenclature

Structure and stratigraphy cannot be separated, and study of either requires careful consideration of the other. A structural emphasis has guided this work, so that stratigraphic nomenclature has not been a major focus of the mapping in the Sheep Range.

Natural lithologic breaks should define map units. Rather than attempting to impose a set of stratigraphic and chronologic units on the Sheep Range sequence, I tried to find readily mappable units and then designated them

by the most appropriate formational names. Some formational divisions have been based on natural lithologic boundaries of regional significance, as in the Eureka Quartzite or the Ely Springs Dolomite. In more variable units, correlation becomes more difficult. In some respects the choice of formation nomenclature is arbitrary, but in all cases readily defined lithologic contacts separate the units. When detailed work resolves the many stratigraphic questions in this part of the Great Basin, revision of the nomenclature may be warranted. Certainly better fossil control will be required, using conodonts and other microfossils.

Table I lists the stratigraphic nomenclature used in the Sheep Range, unit thicknesses, presumed ages, location of the type section of each unit, its distance and direction from the Sheep Range, and a reference to the original description and any significant revisions. Unless specifically mentioned in the description of individual units, ages have been based solely on published data in the literature.

Correlations

Three sections provide the greatest potential for correlation with the Sheep Range (Figure 4). To the

Table I. STRATIGRAPHIC NOMENCLATURE EMPLOYED IN THIS STUDY

Unit	Thickness	Age	Type Section	Direction	Reference
Horse Spring Formation	?100 m	Miocene	St. Thomas Gap	100 km E	Longwell, 1921
Bird Spring Formation	1780 m	Penn-Perm	Goodsprings area	85 km SSW	Hewett, 1931
Indian Springs Formation	30 m	U. Miss	Indian Springs	40 km W	Longwell & Dunbar; Webster &Lane, 1967
Joana Limestone	250 m	L. Miss	Ely District	290 km N	Spencer, 1917
Pilot Shale	15 m	L. Miss	Ely District	290 km N	Spencer, 1917
Devil's Gate Limestone	440 m	U. Dev	NW of Eureka	340 km NNW	Merriam, 1940
Nevada Formation	245 m	L.&M. Dev	Modoc Peak, Eureka	330 km NNW	King, 1878; Hague, 1883; Merriam, 1940
Oxyoke Canyon Sandstone	50 m	L.&M. Dev	Eureka	320 km NNW	Nolan & others, 1956
Beacon Peak Dolomite		L.&M. Dev	Eureka	320 km NNW	Nolan & others, 1956
Laketown Dolomite	300 m	Silurian	Bear River Range, UT-ID border	700 km NNE	Richardson, 1913
Ely Springs Dolomite	140 m	U. Ord	near Pioche	165 km NNE	Westgate & Knopf, 1932
Eureka Quartzite	50 m	M. Ord	Lone Mountain, NW of Eureka	340 km NNW	Hague, 1883; Kirk, 1933
POGONIP GROUP	910 m	L.&M. Ord	SE of Eureka	290 km N	King, 1878
Antelope Valley Limestone	586 m	M. Ord	Eureka	310 km NNW	Nolan & others, 1956
Aysees Peak Member	278 m	M. Ord	Aysees Peak	60 km NW	Byers & others, 1961
Ranger Mountains Member	128 m	M. Ord	Ranger Mountains	60 km WNW	Byers & others, 1961

Table I. (continued)

Unit	Thickness	Age	Type Section	Direction	Reference
Paiute Ridge Member	180 m	M. Ord	Paiute Ridge	85 km NW	Byers & others, 1961
Nopah Formation	300 m	U. Camb.	Nopah Range, CA	110 km SW	Hazzard, 1937
Dunderberg Shale	30 m	U. Camb.	Eureka	320 km NNW	Hague, 1883; Walcott, 1908
Bonanza King Formation	900+m	M.&U. Camb	Providence Mountains CA	250 km S	Hazzard & Mason, 1936
Banded Mountain Member	410+m	M.&U. Camb	Halfpint Range	90 km NW	Barnes & Palmer, 1961
Papoose Lake Member	490 m	M. Camb	Halfpint Range	80 km NW	Barnes & Palmer, 1961
Carrara Formation	265 m	L.&M. Camb	Bare Mountain	125 km WNW	Cornwall & Kleinhampl, 1961
Zabriskie Quartzite	?2 m	L. Camb	Nopah-Resting Spring area, CA	110 km SW	Hazzard, 1937; Wheeler, 1948
Wood Canyon Formation	?200 m	L. Camb ?Precambrian	Wood Canyon, NW Spring Mountains	65 km WSW	Nolan, 1929
Stirling Quartzite	?60 m	?Precambrian	Mt. Stirling, NW Spring Mountains	65 km WSW	Nolan, 1929

Figure 4. Regional Paleozoic Stratigraphy.

Exposed section in four mountain ranges, exclusive of the Eocambrian clastic wedge which crops out only in the Sheep Range and the northwestern Spring Mountains. Sources of data as indicated.

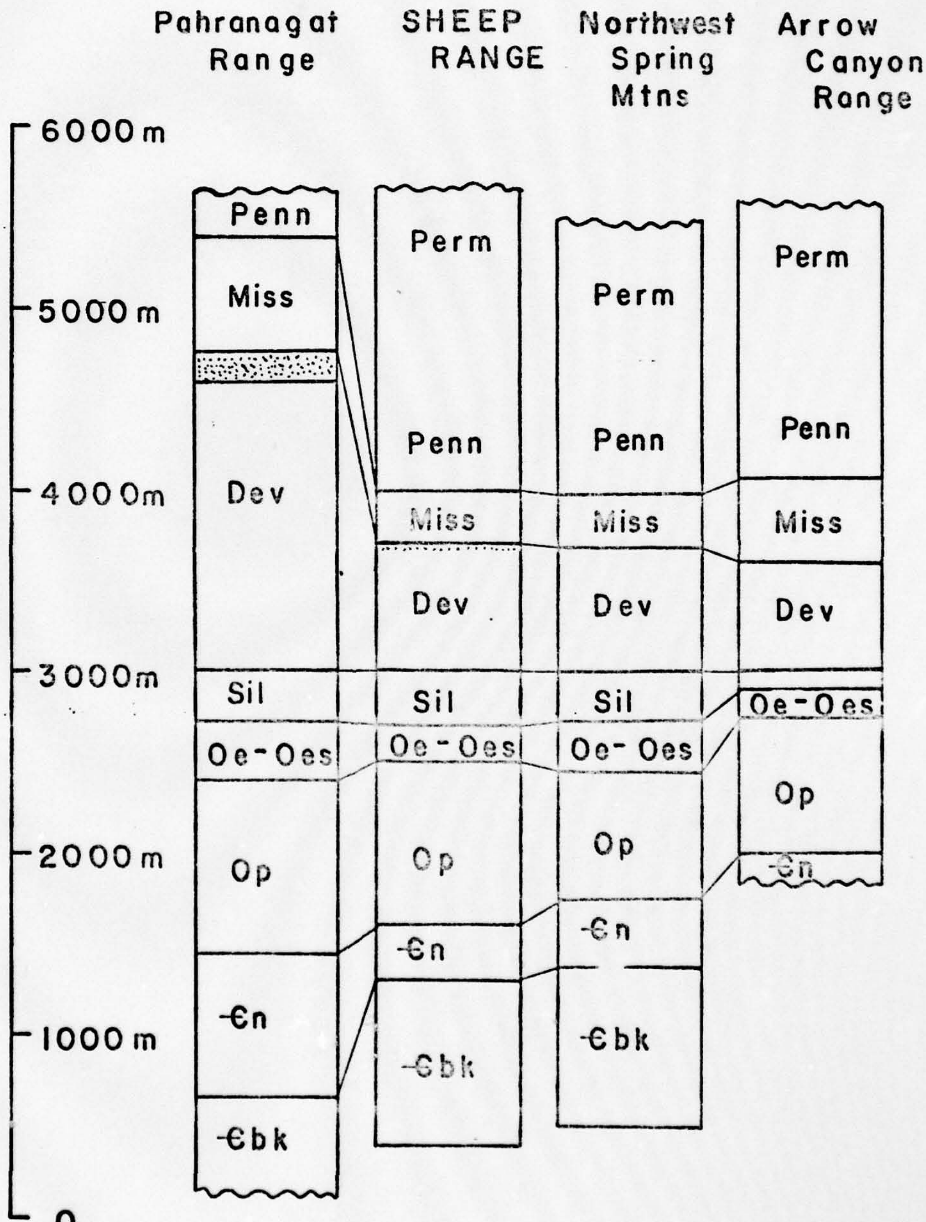
Abbreviations used: Perm, Permian; Penn, Pennsylvanian; Miss, Mississippian; dot pattern, initial influx of clastic Antler flysch; Dev, Devonian; Sil, Silurian; Oe-Oes, Eureka Quartzite and Ely Springs Dolomite; Op, Pogonip Group; Cn, Nopah Formation and equivalents; Cbk, Bonanza King Formation and equivalents.

southwest, Vincelette (1964) discussed the stratigraphy of the northwest Spring Mountains. This area lay along depositional strike from the Sheep Range during the Paleozoic, and thus contains units with similar facies. Except for the upper Devonian and the Mississippian, my usage follows Vincelette. To the east the well studied Paleozoic sequence of the Arrow Canyon Range (Langenheim and others, 1962) represents a more cratonward section that can be compared to the Sheep Range from the youngest Cambrian rocks upward. Nomenclature of rock units in the Sheep Range does not coincide with that of the Arrow Canyon Range for units younger than the Silurian. To the north in the Pahranagat Range, the section measured by Reso (1963) allows comparison although its initial depositional position relative to the Sheep Range remains uncertain. This section ranges in age from the Upper Cambrian into the Pennsylvanian, and differs most from the Sheep Range in rocks of Devonian and Mississippian age.

To the west a complete reference section has not yet been studied. The Specter Range section (Burchfiel, 1964) ranges from upper Precambrian only to the Devonian, but rock units correspond closely with those of the Sheep Range. Other ranges offer comparison for some units, but the absence of work in the ranges adjacent to the Sheep Range complicates correlations. In general usage in the

Figure 4.

Regional Paleozoic Stratigraphy.



Reso, 1963 | this work | Vincelette, 1964 | Langenheim & others 1964

Sheep Range follows that of the U.S.G.S. workers in the Nevada Test Site.

Eocambrian Terrigenous Units

Exposures along the Gass Peak thrust in the Las Vegas Range mark the easternmost exposures of the Eocambrian clastic wedge of the Cordilleran *miogeosyncline*. Thrust plates to the east do not contain rocks of upper Precambrian and Lower Cambrian age, and cratonal sections in the Mormon Mountains or at Frenchman Mountain contain a thin transgressive lower Cambrian succession that rests directly on crystalline basement. In the Spring Mountains the Wheeler Pass thrust is similar to the Gass Peak thrust by carrying a fully developed Eocambrian clastic wedge, and again transition from craton to miogeosyncline cannot be observed. Westward the Eocambrian rocks become thicker and additional units are added at the base. These older formations are not present in the Sheep Range or the Black Hills, but are exposed above a low-angle fault in the Desert Range. To the northeast of the Sheep Range, Stewart (1974) described sections at Delamar and Caliente that contain rocks of the Eocambrian clastic wedge. At each section a significant thickness of basalt (30 m) is present interbedded in the upper Stirling. These rocks may help constrain the

continuation of the thrust belt, specifically the trace of the Gass Peak thrust north from Wamp Spring where it disappears under alluvium.

Eocambrian rock units within the Sheep Range are the Stirling Quartzite, Wood Canyon Formation, a possible feather edge of the Zabriskie Quartzite, and the Carrara Formation. The Carrara represents the transition to carbonate bank deposition that dominated much of the later Plaeozoic. The upper part of the Wood Canyon Formation contains Early Cambrian fossils, but the position of the Precambrian-Cambrian boundary cannot be accurately constrained. On the basis of lithologic correlations, Nelson (1978) proposed that the boundary might occur within the Stirling.

Stewart (1970) measured two sections in the Las Vegas Range in the area mapped by Ebanks (1965). Their thickness estimates for the Stirling and Wood Canyon do not agree. In view of complex slicing of the Eocambrian units in a schuppen zone along the Gass Peak thrust, the estimates can be regarded as only tectonic thicknesses. Poor exposures often do not allow recognition of thrust slice boundaries, so that original stratigraphic thickness cannot be determined. This unfortunate situation means that a comparison cannot be made between the apparently thinner Las Vegas Range section with the Desert Range section to better

understand cratonward thinning within the Eocambrian clastic wedge.

Ebanks (1965) and Halley (1974) described the Carrara Formation in the Gass Peak quadrangle where it is apparently complete. Mapping the Hayford Peak quadrangle shows the Carrara to have different structural styles in its two areas of outcrop. Near Quartzite Mountain the Carrara forms a large ramp anticline but appears structurally simple and coherent. In the Wamp Spring area farther north, repetition of beds by imbricate thrust slices is suggested; although the faults cannot be mapped, outcrop thickness of the Carrara requires structural thickening.

Stirling Quartzite(p€s). The Stirling Quartzite crops out along the base of the Gass Peak thrust at Quartzite Mountain and locally in the Wamp Spring area. Because of complex slicing a complete section of the Stirling could not be recognized. I estimate a thickness of about 60 m for the thickest exposed stratigraphic slice of the Stirling. This compares with Ebank's (1965) estimate of 0-60 m, but contrasts sharply with Stewart's (1970) estimate of 496 m for the Las Vegas Range. Either the Stirling is thicker to the south of the area I mapped, or unrecognized thrust slices occur in some of the covered talus intervals of Stewart's section. In the Spring Mountains Vincelette (1964)

followed Nolan (1929) and reported 975 m of Stirling, but he did not distinguish between exposures along the thrust and those farther west. His estimate corresponds closely to the 952 m thickness of an incomplete section of Stirling in the Desert Ragne (Stewart, 1970), and the 893+ m in the Groom District (Barnes and Christiansen, 1967). Since Vincelette's map shows the absence of the Stirling in places along the thrust contact, I assume that the maximum thickness is developed only toward the west near the type locality of the formation.

The Stirling Quartzite consists of light colored quartzite, in part conglomeratic. Due to the difficulty of recognizing thrust slices in the poorly exposed rocks in the Las Vegas Rnage, I mapped the darker and siltier rocks there as the Wood Canyon Formation, restricting the Stirling to thick-bedded, coarse grained, light colored quartzite usually with distinctive conglomerate beds. The Stirling frequently weathers to a rusty appearance. Clasts within the conglomerates are well rounded, elongated, and up to 10 cm in maximum dimension. They consist mostly of quartz pebbles, but persistent and diagnostic red jasper pebbles also occur. Along the Gass Peak thrust the Stirling becomes highly fractured and vitreous; polished and slickensided surfaces record movement along numerous fault surfaces.

In the absence of a well exposed stratigraphic section,

the contact between the Stirling and the overlying Wood Canyon Formation could be either stratigraphic or tectonic. Locally a tectonic contact is definitely present. The Gass Peak thrust forms the lower contact of the Stirling, as do subsidiary thrusts in the Wamp Spring area.

Wood Canyon Formation (Ꞓwc). As with the Stirling, thickness for the Wood Canyon can only be estimated. A minimum thickness of about 200 m for the Wood Canyon is estimated near Wamp Spring, where it lies conformable below the Carrara Formation but tectonically above the Stirling. Ebanks (1965) measured 410 m of Wood Canyon near Quail Spring in the Gass Peak quadrangle. Stewart (1970) measured only 200 m of the Wood Canyon, along strike about 5 km from Ebank's section. Ebanks noted the thinning along strike of the Wood Canyon, with units presumably missing due to faulting. In the Wheeler Pass plate Vincelette (1964) reported 640-680 m of Wood Canyon, similar to the 620 m measured in the Desert Range (Stewart, 1970) or the 696 m measured in the Groom District (Barnes and Christiansen, 1967).

Variable lithologies make up the Wood Canyon Formation. Siltstone and quartzite predominate, although minor shale and one thin dolomite bed are also present. The Wood Canyon weathers to form dark rounded hillocks and slopes,

in contrast to the more massive light colored outcrops of the Stirling. Rocks in the Wood Canyon frequently have well developed small scale cross-bedding or are well laminated and contain other sedimentary structures. Compared to the Stirling, the Wood Canyon is usually finer grained, thinner bedded, and darker in color, usually weathering to gray, purple, brown, tan, and maroon. Near the top of the formation, a thin bid of dark brown dolomite occurs that contains small black organic remains, which weather to leave a pitted surface. It contains olenellid trilobite fragments and abundant echinoderm debris. J. Wyatt Durham (personal communication, 1977) examined the dolomite and observed probable eocrinoid plates (diameter ± 6 mm), smaller unidentifiable fragments, trilobite remains, and one large plate (diameter ± 14 mm) suggestive of a carpoid or a cystoid.

Near Wamp Spring the Wood Canyon contains thick clastic sediments with an abundant trace fossil community. C. Kent Chamberlain (pers. Comm., 1978) identified Cruziana and Rusophycos. In addition the area yielded a complete cephalon of the olenellid trilobite identified as Judomia (?) gracile (C.A. Nelson, pers. comm., 1979). This species occurs in the upper part of the Fallotaspis zone (Nelson, 1976), establishing the lower Cambrian age for the upper part of the Wood Canyon.

Zabriskie Quartzite. The feather edge of the Zabriskie Quartzite may be exposed in the Las Vegas Range. Near Wamp Spring approximately 1 m of light colored, vitreous quartzite occurs above siltstones and quartzites of the Wood Canyon and below shales of the Carrara. This unit does not occur throughout the mapped area, although to the south in the Gass Peak quadrangle Stewart (1970) reported 4 m of Zabriskie (?) Quartzite near Quail Spring. If actually the Zabriskie, the Las Vegas Range section contains a thickness of Zabriskie comparable to the undoubted 2 m thickness in the Desert Range (Stewart, 1970), which lies to the west in the direction of increasing thickness for the Zabriskie. Ebanks (1965) considered the Zabriskie to be absent in the Las Vegas Range, where Stewart measured his section. Vincelette (1964) reported 6 m of Zabriskie at the top of the Wood Canyon in the northwest Spring Mountains, but did not map it separately. Where present in this part of the geosyncline, the Zabriskie must originally have been very thin. It could be absent along strike due to original non-deposition or tectonic slicing along the trace of the Gass Peak thrust.

Halley (1974) proposeda redefinition of the Zabriskie, assigning additional strata to the unit from the overlying Carrara. I have not adopted his definition, and have mapped the thin Zabriskie Quartzite with the Wood Canyon.

The thin light to medium brown, vitreous quartzite at the top of the Wood Canyon is correlated with the Zabriskie. The unit contains animal trails oriented horizontally on bedding planes. The rock types above and below this quartzite (or the Wood Canyon-Carrara contact where the Zabriskié was not noted) change; in the Wood Canyon below, the dominant lithologies are quartzite and siltstone whereas in the Carrara above, the dominant lithologies are green, red, and purple shales that contrast with the drab brown and purple of the Wood Canyon.

Though lacking diagnostic body fossils, the Zabriskie Quartzite clearly is of Early Cambrian age because olenellid trilobites occur above and below it.

Carrara Formation (€c). The Carrara Formation forms a transition from terrigenous sedimentation in the Eocambrian to carbonate sedimentation that characterized the rest of the Cambrian and much of the later Paleozoic. Near Quail Spring, Ebanks (1965) measured 206 m of the Carrara whereas Halley (1974) measured 265 m of rocks that correspond to what I mapped as Carrara. Halley included 48 m of rock in his Eagle Mountain Member of the Zbriskie, which I place in the Carrara, and did not map. Unfortunately in the Wamp Spring area the Carrara appears to be tectonically thickened, and the cross section could not be used to

estimate a thickness.

The Carrara Formation consists of interbedded shale and limestone, with shale predominating at the base and mostly limestone at the top. In the Las Vegas Range, four limestone and four shale members can be recongized (Halley, 1974). These members were not mapped, although the alteration of lithologies was clearly evident. In all members both shale and limestone occur, usually with one subordiante to the other. Shales weather to platy fragments, at times developing good cleavage. Colors range from green to red. Despite repreated searching, no fossils were found in the shales. Limestone, especially in the lowerpart of the Carrara, contains abundant silt and weathers to buff or orange. Pisolitic structures, usually identified as Girvanella, commonly occur in the Ca ra limestone and locally form more than 50 percent of the rock.

Fossils, especially trilobite fragments, occur in the limestone beds of the Carrara. In the lower part of the formation, the distinctive outline of the olenellid Bristolia can be identified by its advanced genal spines. One limestone hash bed contained the trace fossil Monorphicnus (C.K. Chamberlain, pers. Comm., 1978). From regional studies the Early-Middle Cambrian boundary lies within the Carrara (Palmer, 1971).

Depositional Grand Cycles

Aitken (1968) proposed the concept of the grand cycle to account for large scale cyclic variation in sedimentation during Cambrian and Ordovician time in the Canadian Cordillera. A grand cycle starts with the deposition of terrigenous sediments belonging to the inner detrital facies belt. Gradationally these pass upward into carbonate deposits typical of the middle carbonate belt. Clastics of the next grand cycle abruptly overlie the shallow water carbonates. Aitken recognized eight grand cycles from the Middle Cambrian to the Middle Ordovician, ranging in thickness from 275 to 760 m. Aitken later (1978) published a modification of his model, which has proved extremely useful in looking at the Cambrian record in the Cordilleran geosyncline.

Halley (1975) demonstrated that the Carrara consisted of three grand cycles, and near the Sheep Range a fourth grand cycle is recognized that continues into the Bonanza King Formation. Two additional grand cycles occur in the higher part of the Cambrian: one starts with the calcareous siltstone unit at the base of the Banded Mountain Member of the Bonanza King, and the second starts with the Dunderberg Shale at the base of the Nopah Formation. In both of these cycles the lower clastic part is very thin compared

to the upper carbonate part and comprises essentially a brief influx of terrigenous material onto the carbonate platform.

Ordovician cycles have not received the attention given to Cambrian cycles, although Aitken (1966) originally defined two grand cycles within the Ordovician. Yet within the Sheep Range the regular influx of silt into the predominately carbonate sequence created lithologic boundaries that can be readily mapped. These silt influxes occur at four places within the Pogonip: at the base of the group (which may actually be latest Cambrian in age), at the base of the Paiute Ridge Member, at the base of the Ranger Mountains Member, and within the Aysees Member which was recongized but not mapped. Silty dolomite in the upper Aysees Member was followed by the influx of quartz sand forming the widespread Eureka Quartzite, which marked a change in depositional patterns.

Above the Eureka Quartzite, dolomite deposition (or alteration) dominates through the Ely Springs Dolomite (upper Ordovician) and the Laketown Dolomite (Silurian). Influxes of silt mark the Beacon Peak Dolomite member of the Nevada Formation, the base of the Devil's Gate Limestone, the Pilot Shale, and the Indian Springs Formation. These later Paleozoic interruptions of carbonate deposition may represent different phenomena that the beginnings

of the lower Paleozoic grand cycles, since deposition of the Pilot Shale and the Indian Springs Formation are related to terrigenous material shed eastward from the Antler orogenic highlands.

Bonanza King Formation. The Bonanza King Formation consists of predominately limestone and dolomite that gradationally overlie the Carrara's upper most limestones. I mapped the contact at the change from silty, bench-forming limestone of the Carrara to pure, more massive carbonate rocks of the Bonanza King. An estimated thickness of 900 m for the Bonanza King agrees with the same figure given by Ebanks (1965) and the 853 m measured by Vincelette (1964) within the Wheeler Pass thrust plate. The Bonanza King thickens to the west: Palmer (1979) reports 1000 m in the Desert Range, while Barnes and Christiansen (1967) report 1327 m at Groom.

The estimate of 900 m for the formation represents a minimum thickness. The estimate of 490 m for the lower Papoose Lake Member should be valid, but the 410 m for the Banded Mountain may be too low. In the Desert Range the Banded Mountain is about 100 m thicker than the Papoose Lake, while at Groom it is 60 m thicker than the Papoose Lake. As is evident from the geologic map (Plate I), a continuous section of the Bonanza King Formation is not

present in the Sheep Range. The Papoose Lake and only the lower part of the Banded Mountain crop out in the Las Vegas Range. Along the west side of the Sheep Range at least 410 m of the Banded Mountain crop out, but the rocks there are faulted and repeated. Thus an accurate thickness cannot be determined.

<u>Papoose Lake Member (€bp)</u>. The Papoose Lake Member consists of 490 m of limestone and dolomite, with rare silty dolomite. Much of the member contains laminated or mottled, dark and light gray limestone and dolomite. Sedimentary structures indicative of very shallow water deposition are abundant and well preserved but were not studied in detail. No fossils were found in the Papoose Lake. The abrupt change to silty carbonate marks the upper contact with the Banded Mountain Member.

<u>Banded Mountain Member (€bb)</u>. A bench-forming, silty dolomite marks the base of the Banded Mountain Member. This unit weathers buff to purple or red, and weathers into small, slabby blocks forming talus slopes above massive cliff-forming rocks of the Papoose Lake Member and below bench-like cliffs of the Banded Mountain. This basal unit is of regional extent. Barnes and Palmer (1961) mentioned it in their initial subdivision of the Bonanza King. Since

that time it has been recognized over a wide region, and has proved especially important in mapping the more eastern thrust faults in the Sevier orogenic belt which appear to detach in horizons near the silty unit for long distance along strike. Burchfiel and others (1974) noted stratigraphic control near this horizon for 60 km along the Keystone thrust; more recent work significantly extends this distance. In the Las Vegas Range and elsewhere, the silty unit contains small brachiopods and trilobites of the <u>Ehmania-Ehmaniella</u> radiation, establishing a Middle Cambrian age.

Above the basal silty dolomite unit, the Banded Mountain Member consists of light and dark banded limestone and dolomite. The bands are commonly on the order of 1-3 m thick and range from white to dark gray and black, with a brownish cast to some of the darker bands. From a distance the prominent color bands and ledges give the member its characteristic appearance. Like the Papoose Lake Member, the carbonate rocks of the Banded Mountain Member were deposited in shallow-water sedimentary environments. Well-preserved sedimentary structures such as burrow mottling, edgewise conglomerate, laminations and stromatolites abound.

On the west side of the Sheep Range and the Black Hills, the bulk of the uppermost Banded Mountain consists

of dolomite. But near the northern edge of the mapped area, in very rugged outcrops north and south of Deadman Canyon and the Hidden Forest road, the uppermost beds beneath the Dunderberg Shale consist of oolitic limestone. Everywhere along the west side of the Sheep Range or the Black Hills, whether this interval consists of limestone or dolomite, the contact with the Dunderberg is sharp and easily mapped.

Nopah Formation (Ꞓn). The Nopah Formation is upper Cambrian, but due to widespread dolomitization fossils are scarce and the basal Pogonip may include the youngest Cambrian beds (A.R. Palmer, pers. comm., 1979). The Nopah can be divided into a basal Dunderberg Shale member and an upper undifferentiated unit. The Halfpint and Smoky Members of Christiansen and Barnes (1966) cannot be distinguished in the Sheep Range.

Dunderberg Shale (Ꞓnd). A sudden influx of fine terrigenous material forming shale and shaly limesonte succeeded the carbonate sedimentation of the Bonanza King. These beds are correlated with the Dunderberg Shale Member, and form an even more widespread unit than the silty dolomite at the base of the Banded Mountain. The 30 m thick Dunderberg consists of two parts. In the lower part, shale and

limestone occur in about equal amounts although the limestone beds weather to form much more prominent outcrops. The limestone typically forms small ledges,separated by float of small shale chips. Shales in this part of the member are hard, fissile, and are olive to green or gray, whereas limestone interbeds weather gray to orange. The upper part of the Dunderberg consists of a greater proportion of limestone, with silty limestone interbeds. Most of the limestone contains a *significant proportion of silt*. These rocks corresponds to unit 39 of Barnes and Christiansen (1967), which they placed in their Halfpint Member. I have placed these rocks with the shalier Dunderberg below, because both parts contain a significant proportion of silt and weather into a slope beneath the massive dolomite upper unit which forms rugges cliffs. Additionally, from a practical standpoint the two units together have sufficient thickness to be easily mapped, whereas individually they could not be separated at the scale of the map. Ebanks (1965) and Burchfiel and others (in prep.) also placed this upper unit in the Dunderberg.

In both parts of the Dunderberg, limestone nodules occur. These have irregular, elliptical outlines, flattened parallel to bedding. The Dunderberg contains abundant brachiopod and trilobite debris. From Dunderberg outcrops in the Gass Peak quadrangle, Ebanks collected trilobites

identified by A.R. Palmer (pers. comm. to Ebanks, 1965) as Elburgia quinnensis (Resser), Strigambitus? blepharina Palmer, and a probable indeterminate dokimocephalid. The fossils indicate a Late Cambrian age.

Nopah Formation Undifferentiated (Єn). Above the Dunderberg Shale Member, the remainder of the Nopah Formation, an unnamed and undifferentiated upper member, consists of massive dolomite. The most conspicuous features of the Nopah are its black and white bands which are thicker and more conspicuous than those in the Bonanza King Formation.

In the southern part of the mapped area, east of Joe May Canyon, the Nopah consists of two black stripes separated by a white stripe. Each stripe is about 90 m thick. Rocks of the Nopah Formation climb to higher elevations toward the north, and the bands become less distinct due to increasing vegetation. The stripes can no longer be distinguished from a distance as they can in unvegetated exposures. The color bands also change, chiefly by northward thinning of the central white band. In the area around Deadman Canyon, the Nopah consists essentially of black dolomite with a thin (25 m) white streak in the center. In the Black Hills, the western fault block contains the typical three bands, black-white-black, while the eastern fault block contains a large number of poorly

defined bands, with the dark colors dominating.

Both light and dark dolomites are present on a finer scale within the large bands. The Nopah contains laminated and mottled dolomite. In places sedimentary structures are well preserved, especially in the northern part of the mapped area near Deadman Canyon. Elsewhere the Nopah has been strongly recrystallized and consists largely of coarsely crystalline dolomite. The Nopah forms steep cliffs, which resemble similar black dolomite cliffs formed by the Ely Springs Dolomite. Cliffs of the Nopah and Ely Springs provide the most impassable topography in the Sheep Range. The Ely Springs can readily be identified by its common fossils.

Near the top of the Nopah, small sandy nodules about 1 cm in diameter are present. Larger associated chert nodules stand out much more conspicuously than the sandy nodules. The chert forms abundant nodules and thin discontinuous beds in the upper 15-20 m of the Nopah. The dark chert frequently weathers to form rusty outcrops. The top of the Nopah was drawn at the top of this cherty, dark dolomite.

Large algal heads were the only fossils observed in the Nopah.

Ordovician Units

Ross (1964) measured a section of the Ordovician rocks in Black Gate Canyon (named for pillars of the Ely Springs Dolomite), on the southern edge of the mapped area. Ross noted the extreme dolomitization of the Pogonip Group, the general lack of fossils, and the difficulty in correlating the subdivisions of the Pogonip with other sections. Above the troublesome Pogonip, the upper Ordovician formations represent some of the most widespread units within the southern Cordilleran miogeosyncline. Atop silty carbonates of the Pogonip, the white-black couplet of the Eureka Quartzite and the Ely Springs Dolomite forms one of the most distinctive sequences, recognizable from adjacent mountain ranges.

Pogonip Group

Four orange-weathering silty carbonate intervals help differentiate the Pogonip Group into mappable subdivisions. Lacking fossil evidence from the lower part of the sequence and given extreme variation in lateral facies within the Pogonip, correlation with other well known sections is difficult. Examination of the many quadrangle maps published in the Nevada Test Site shows

this problem. Mapped thicknesses of subdivisions within the Pogonip vary greatly, as do their lithologies. In the Arrow Canyon Range, Langenheim and others (1962) divided the Pogonip into six informal units designated Opa to Opf. Contrary to the statement by Stricker and Carozzi (1973, where names and correlations are ascribed to Langenheim, in press) formal correlation and naming of the Arrow Canyon Ordovician is still in progress.

My estimate for the thickness of the Pogonip is 910 m and is significatnly thicker than the 732 m measured by Ross (1964). Our estimates for the lower undifferentiated unit agree closely, 324 m and 311 m. For the Paiute Ridge and Ranger Mountains Members we have the greatest difference. I estimate 308 m and Ross measured 171 m for the two members combined. Variation along strike in the outcrop thickness of these two shaly carbonate members is present and I suggest that my thickness may more closely represent the depositional thickness. For the upper most Aysees Member, Ross measured 250 m and included an unknown amount of section missing at a fault, so that my estimate of 278 m could be in substantial agreement.

In the Spring mountains, Vincelette (1964) did not attempt to Subdivide the 366-701 m of Pogonip present. In the Pahranagat Range, Reso (1963) divided 957 m of Pogonip into three limestone formations with five members, but none formally named. Ross (1970) published a section in

the Pahranagat Range that used the formation names from the Eureka District (Nolan and others, 1956), which have also been used in the Nevada Test Site.

Four units were mapped in the Sheep Range. The upper three are correlated with the Antelope Valley Limestone and its three members. The lower unit does not correlate easily with the other formations used in the Eureka District, either the Ninemile Shale which appears to be absent or the underlying Goodwin Limestone. The Goodwin and the Ninemile can be recognized at Pahranagat and the Nevada Test Site, but could not be distinguished at Arrow Canyon (Stricker and Carozzi, 1973). Thus the lower unit was considered as Pogonip undifferentiated. In the Black Hills this lower Pogonip unit consists of markedly different facies from the Sheep Range only 7.5 km to the east. In the Black Hills the Pogonip undifferentiated can be divided into two subunits. These subdivisions do not correspond, however, to the Goodwin or Ninemile formations.

Pogonip Group Undifferentiated, Lower Subunit (Opl). This subunit occurs only in the Black Hills, where it consists of two parts: a lower silty, orange-weathering dolomite, and an upper dark, cliff-forming dolomite. To the east in the Sheep Range, the cliff-forming black dolomite is not present and rocks similar to the upper subunit rest directly on the silty dolomite at the base of the lower

part of the lower subunit. This basal silty dolomite can be traced in the Sheep Range, but its thinness precludes mapping it separately.

The base of the Pogonip represents an abrupt transition in color, lithology, and characteristic outcrop from the underlying Nopah Formation. The Pogonip consists of light gray to orange-weathering dolomite. The basal Pogonip contains abundant silt and forms a slope or slight bench above the cliffs of the Nopah.

Above the basal silty beds is a massive black dolomite that closely resembles dolomites of the Nopah Formation and forms similar cliffs. This dark dolomite forms the bulk of the lower subunit of the Pogonip Group undifferentiated. This subunit could be placed within the underlying Nopah, based on the similarity of the cliff-forming dolomite with the Nopah. This would also require that the silty dolomite belong to the Nopah. No other sections of the Nopah Formation include silty, light colored dolomite above the horizon of the Dunderberg. Therefore this possibility is rejected.

Furthermore, in the Sheep Range, the silty beds directly underlie distinctive Pogonip rocks without an intervening black dolomite. Because silt-bearing intervals appear widespread and correlatable, the lowest one is taken as the base of the Pogonip. This leaves unresolved the

problem of the rapid facies change in the basal Pogonip, a question that could be resolved by work in the Desert Range. This facies difference implies that structural reconstructions that restore the Black Hills to a position immediately adjacent to the Sheep Range must account for the rapid facies change.

Pogonip Group Undifferentiated, Upper Subunit (Opu). Above the cliffs of the lower subunit are light gray, cherty, well bedded dolomites of the upper subunit. A sharp contrast in color accompanies a break in slope. The upper subunit forms steep slopes above the cliffs of the lower subunit, with bedding that forms conspicuous ledges visible from a distance.

Pogonip Group Undifferentiated, Sheep Range (Op). In the Sheep Range the two subunits of the Pogonip Group undifferentiated cannot be separated due to the absence of the black cliff-forming dolomite that is present in the Black Hills. Total thickness of the Pogonip Undifferentiated, 343 m, remains nearly constant between the Sheep Range and the Black Hills due to increased thickness of the medium to light gray dolomites above the basal silty dolomite. The silt-bearing beds in the Sheep Range closely resemble the same interval in the Black Hills. Above this

unit, the Pogonip undifferentiated in the Sheep Range contains abundant intraformational conglomerates that consist of angular breccias of dolomite and chert, cemented in a dolomitic matrix. Both dolomite and chert must have lithified prior to brecciation, at least sufficiently to be able to form angular clasts. Much of the brecciation could be due to storm activity, as suggested by Stricker and Carozzi (1975) for breccias in the Pogonip of the Arrow Canyon Range. Some brecciation could also result from tectonic processes, especially intraformational slip to take up rotation of the Sheep Range to be discussed later.

No fossil material was found in the Pogonip Group undifferentiated, either in the Sheep Range or the Black Hills. In the Desert Range, the lowermost beds of the Pogonip contain latest Cambrian fossils (A.R. Palmer, pers. comm., 1979).

Antelope Valley Formation (Oa). Correlation of the 586 m thick Antelope Valley Formation remains poorly constrained. Trilobites from the two lower silt-bearing members mapped here in the Antelope Valley Formation were examined by R.J. Ross, Jr. (pers. comm., 1979) and found to represent a fauna characteristic of the Antelope Valley rather than the older Ninemile Shale. Apparently the Ninemile Shale

with its characterisitc and distinctive fauna does not occur in the Sheep Range. The Antelope Valley contains three silt-bearing carbonate intervals that define the mapped members. The formation was mapped only where vegetation obscured contacts between the members.

Paiute Ridge Member (Oap). Light colored, orange-weathering silty dolomite marks the base of the Paiute Ridge Member. The lower part of the Paiute Ridge Member forms a slight bench above the Pogonip undifferentiated. Above the basal silty dolomite, the remainder of the Paiute Ridge Member consists of silty, cherty light gray dolomite and limestone. Significant limestone appears in the upper part of the member near Deadman Canyon, whereas elsewhere dolomite dominates. Silty carbonate is present throughout, but decreasingly less important upward. The member is about 180 m thick.

Range Mountains Member (Oar). The Ranger Mountains Members consists mainly of silty dolomite and limestone, 128 m thick. This cliff-forming unit contrasts sharply with the slope-forming upper part of the Paiute Ridge Member, except in canyons with ponderosa forest and consequent poor outcrop. The Range Mountains Member contains both limestone and dolomite, with limestone probably the dominant lithology.

Similar to the Paiute Ridge, limestone content appears to increase northward in the Sheep Range. The Ranger Mountains Member weathers more reddish than the Paiute Ridge, and crepe weathering is common. The Ranger Mountains Member forms the only resistant silty carbonate unit in the Sheep Range.

Aysees Member (Oaa). The base of the Aysees Member is marked by a sharp transition from silty carbonate to medium or dark massive dolomite. This member contains two distinctive lithologies. The lower part is formed by a medium gray cliff of structureless dolomite, with the upper half containing abundant, sometimes closely packed pisolites usually referred to Girvanella. Near the top of the dark dolomite, large gastropods are concentrated on many of the bedding planes. They belong to the genera Palliseria and Maclurites (Ross, 1964), and sometimes occur as internal molds, but more often as cross sections through the shell. The shells consist of lighter colored recrystallized carbonate crystals which stand out from the darker matrix. Shell diameters range up to 10 cm, earning the snails the field nickname "Big Macs." Much less commonly the sponge (?) Receptaculites occurs in the same beds.

Above the cliff-forming dark dolomite, another interval of silty dolomite forms the upper part of the Aysees

Member and the top of the Pogonip Group. This dolomite appears transitional to the Eureka Quartzite, and similar to other silty dolomites of the Pogonip. Several small bodies of quartz sand, apparently channels, occur within the upper Aysees Member.

Eureka Quartzite (Oe). The Eureka Quartzite rests with sharp contact on the silty dolomites of the upper Aysees Member of the Pogonip Group. In exposures north of Twin Buttes on the east side of the Sheep Range, the contact appears gradational over perhaps a meter. In contrast the contact on the western side of the range shows no sign of gradation, and is usually poorly exposed. The general nature of the contact suggests that bedding plane slip has occurred along this lithologic b[illegible].

An average thickness of 50 m is estimated for the Eureka, similar to the 52 m measured by Ross (1964) in Black Gate Canyon. F.G. Poole (pers. comm., 1979) measured 64 m of Eureka in Ewe Canyon just south of the mapped area. The variation in thickness over such a short distance (less than 2 km) in a unit as distinctive as the Eureka with its sharp upper and lower contacts, supports the suggestion that bedding plane faults are present along the contacts. Poole noted evidence for a disconformity at the top of the Eureka section, whereas Ross observed a

fault of probably small displacement. Bedding plane faulting clearly cuts out the Ely Springs along the crest of the Sheep Range to the north of the two measured sections, and could also account for the repetition of the Eureka just south of Sheep Peak.

The Eureka consists primarily of white to brown, vitreous, fine to medium grained orthoquartzite. Bedding is usually not conspicuous, either due to brecciation or initial absence and cross-bedding occurs sporadically. Less abundant rock types include dolomitic quartzite, some beds of dolomite in the middle part of the formation, and particularly a multi-colored quartzite which weathers rust, red, or yellow. Generally the Eureka forms a resistant unit, but because it underlies a more resistant unit, the Ely Springs Dolomite, the outcrops are often obscured by talus.

Ely Springs Dolomite (Oes). Above the Eureka lies the equally distinctive Ely Springs Dolomite. Even where the contact with the Eureka is gradational over a few meters, the base of the Ely Springs is often sharply defined by black dolomite overlying white quarztzite. Along the west side of the Sheep Range, slip along the contact has apparently obscured the gradational beds between the Eureka

and the Ely Springs. West of the Mormon Well Road on the east side of the range, gradational contacts crop out. Above pure white quartzites of the Eureka, a thin transitional zone of sandy dolomite quickly passes upward into pure dark gray to black dolomite over a distance of about a meter.

The Ely Springs forms cliffs similar to the Nopah, and these dolomites are more resistant to erosion than the Eureka. Talus from the Ely Springs frequently covers its basal contact and parts of the Eureka. Near the southern edge of the map on the west side of the range, several slide blocks of Ely Springs resting on beds of the Eureka were mapped. Similar relations, but on a smaller scale and unmappable are present elsewhere in the Sheep Range.

The Ely Springs generally consists of massively bedded, fine grained very dark dolomite. Chart appears in the lower part of the section as nodules and stringers. Higher in the section abundant white dolomite blebs occur in the dark dolomite. Much of the Ely Springs releases the pungent odor of hydrogen sulfide from fresh surfaces. Upward the Ely Springs becomes lighter in color, and the upper contact is difficult to define (see below).

Fossils present in the Ely Springs include solitary horn corals, medium sized colonial corals, pelmetazoan columnals (including star-shaped columnals with a round

central lumen), Receptaculites, and others. While never particularly abundant, fossils can usually be found, especially the corals, and serve to clearly distinguish the Ely Springs from the similar black dolomites in the Nopah Formation.

Laketown Dolomite (Sl). The Silurian rocks disappear first below the regional Sub-Devonian unconformity, with the Ely Springs, Eureka, and Pogonip persisting farther toward the craton in the east. Regional relationships of Silurian rocks in the southern Great Basin have not been investigated in detail, so that stratigraphic nomenclature remains somewhat open. Figure 5 shows the Silurian nomenclature for four ranges: the Arrow Canyon, Pahranagat, Spotted, and Sheep Ranges. Particularly important are the periods of non-deposition, established by Poole and others (1977) whose presence or absence has not been established for the Sheep Range. The divisions shown represent only lithologic correlations.

The only clear lithologic break in the Sheep Range stratigraphic section above the Ely Springs Dolomite is at the base of the Beacon Peak Dolomite Member of the Nevada Formation. The light colored dolomites have a readily defined lower contact that is a color contrast with the dark Ely Springs, and their upper contact is

Figure 5. Silurian and Devonian Nomenclature and Correlations.

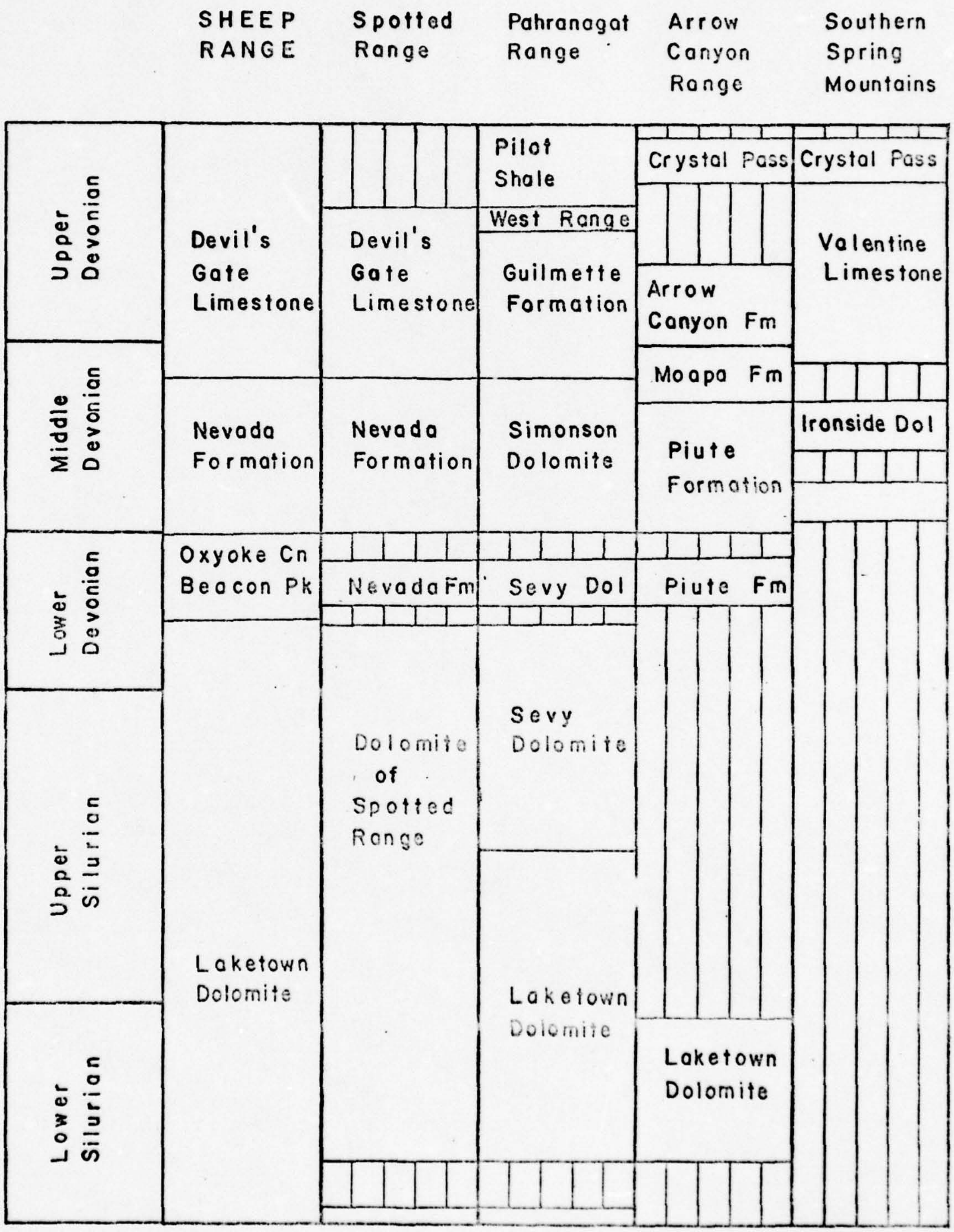
Formational nomenclature used in the Sheep Range and four adjacent mountain ranges. Periods of non-deposition and eroison are indicated by vertical ruling. Lack of these hiatuses in the Sheep Range merely reflects current ignorance of their timing and extent. Unlabelled units at the base of the Lower Silurian in the Spotted and Pahranagat Ranges are beds of the uppermost Ely Springs Dolomite. Unlabelled unit in the southern Spring Mountains has been variously assigned to the Goodsprings Dolomite or the Mountains Springs Formation. After Poole and others, 1977.

is taken as the appearance of orange-weathering silty dolomite in the Beacon Peak. The Silurian and Lower Devonian (if present) rocks in the Sheep Range are 300 m thick, a thickness that corresponds most closely with sections to the east where the term Laketown Dolomite has been used. In the Arrow Canyon Range, the Laketown has a thickness of 152 m (Langeheim and others, 1962); in the Delamar Range, 296 m (Heckel and Reso, 1962), and in the Pahranagat Range, 224-286 m (Reso, 1963). Vincelette (1964) reported up to 274 m of Silurian undifferentiated in the northwestern Spring Mountains, similar to the Sheep Range Thickness. To the west Christiansen and others (1966) reported 439 m for the dolomite of the Spotted Range, while Burchfiel (1964) reported a much thicker 693 m for Silurian undifferentiated rocks in the Specter Range.

The dolomite of the Spotted Range contains Lower Devonian rocks, as does probably Burchfiel's Specter Range unit. This time interval is absent at Arrow Canyon, but present at Delamar and Pahranagat as the Sevy Dolomite: 240 m at Delamar (Heckel and Reso, 1963), and 368-439 m at Pahranagat (Reso, 1963) [in both these sections, the thickness corresponding to the overlying Beacon Peak Dolomite and Oxyoke Canyon Sandstone has been subtracted]. Osmond (1962) reported 65 m of the Sevy below its upper sandy member (23 m) in the southern part of the Sheep Range.

Figure 5.

Silurian and Devonian Stratigraphic Nomenclature.



after Poole & others, 1977

Because I could not map the Sevy, it was not differentiated from the Laketown.

When the Silurian and Lower Devonian rocks in the Sheep Range are compared with the thickness in other nearby sections, the Sheep Range has a considerably thinner sequence than all other ranges except the northwestern Spring Mountains, which occupied a position along depositional strike, and the Arrow Canyon Range section, which is half as thick. These observations suggest that the 300 m interval in the Sheep Range represents mostly the Silurian, and should be correlated with the Laketown Dolomite. Correlation with the dolomite of the Spotted Range is also possible (F.G. Poole, pers. comm., 1979), but until that unit is formally named and better fossil control exists correlation of the Silurian rocks with the Laketown Dolomite is favored.

Both the upper and lower contacts of the Laketown are gradational, but usually easily defined. The generally light colored dolomites of the Laketown contrast sharply with the dark dolomites of the Ely Springs. A recessive, argillaceous dolomitic unit is sometimes present at the top of the Ely Springs, and where present its top was taken as the base of the Laketown (Chamberlin and Langeheim, 1971). Where these rocks were not present, as is the general case, the change from massive dark dolomite of the Ely Springs to more evenly bedded light dolomite was taken as

the contact. This contact may not precisely locate the Ordovician-Silurian boundary; Poole and others (1977) indicated that the top of the Ely Springs ranges into the lower Silurian. The upper contact of the Laketown was taken as the change from dolomite to orange-weathering silty dolomite.

The bulk of the Laketown consists of light gray to cream colored dolomite, although near the middle of the formation a prominent darker band appears. The dolomite is usually fine grained, and in places vuggy. Minor chert occurs in the Laketown, especially in the darker dolomite near the center of the formation. At the southern end of the mapped area in Long Valley, extremely cherty beds occur near the top of the formation where chert nodules lie in beds within the medium gray dolomite. These cherty beds could not be traced northward along strike, because they disappear in dip slopes covered by dense ponderosa forest.

Fossils in the Laketown generally show poor preservation. Large colonial coral heads are most frequent. Near the base of the formation, some beds contain abundant brachiopods. At places concentrations of pelmetazoans occur, and probable stromatoporoids occur in the upper part of the Laketown.

Devonian Formations

Regionally, the Sheep Range is in an area where four different sets of formational names for the Devonian could be used (see Figure 5). To the west in the Nevada Test Site and in the Specter Range (Burchfiel, 1964), the Nevada and Devil's Gate formations have been used, extending their usage from type areas in the Eureka District. To the south in the Spring Mountains, in thrust plates below the Wheeler Pass thrust Devonian rocks are assigned to the Sultan Formation of Hewett (1931). In the Wheeler Pass plate Vincelette (1964) mapped both the Nevada and Sultan formations. Ebanks (1965) mapped the Devonian in the Las Vegas Range as Sultan without detailed investigation. To the east in the Arrow Canyon Range, L nheim and others (1962) named new formations. Northward in the Pahranagats, Reso and Croneis (1959) and Reso (1963) divided the thick Devonian section into units recognized in Utah: Sevy, Simonson, and Guilmette formations.

Formations mapped in the Sheep Range best correlate to the Nevada and Devil's Gate formations of the Eureka District. More cratonward rocks best correlate with the Sultan which represents a different facies of Devonian rocks; its members cannot be readily distinguished in the Sheep Range. The Arrow Canyon section also lies more

cratonward, is slightly thinner (600 m compared to 685 m), and the formations defined by Langenheim and others have not yet been used in mapping beyond the immediate vicinity of measured sections. Their Piute Formation corresponds to the Nevada, and their three upper formations correspond to the Devil's Gate. The Pahranagat Devonian rocks are more than twice the thickness of those in the Sheep Range, and the Guilmette there can be lithologically correlated with the Devil's Gate and the Simonson with the Nevada. However I was unable to separate a Sevy Dolomite from the Lake town-- no mappable lithologic contact exists at the proper stratigraphic level in the Sheep Range. If rocks of the appropriate age occur in the Sheep Range, lithologically they belong with the Laketown, a relation similar to that present in the Spotted Range as discussed earlier.

Nevada Formation (Dn). The Nevada Formation can be divided into two units. The lower unit corresponds to the Beacon Peak Dolomite and Oxyoke Canyon Sandstone members of the Eureka District (Nolan and others, 1956), which possess distinctive lithologies but insufficient thickness to map separately. The upper unit corresponds to the remainder of the Nevada without differentiated members.

Oxyoke Canyon Sandstone-Beacon Peak Dolomite (Dnob). The base of the Beacon Peak Dolomite forms a recessive slope above the more resistant dolomites of the Laketown. This basal unit consists of olive-weathering, silty dolomite. The upper part of the Beacon Peak contains abundant elongated nodules of dark grey chert in a fine grained medium gray dolomite matrix.

The Oxyoke Canyon Sandstone consists of interbedded quartzite, sandy dolomite, and dolomite. The Oxyoke Canyon contrasts strongly with other quartzites in the Sheep Range which are purer quartzite. The Eureka contains minor dolomite, but in the Oxyoke Canyon dolomite generally dominates and sandy dolomite is common. The Oxyoke Canyon weathers light tan or rust, whereas the quartzite weathers near white and the dolomite gray. I mapped the top of the Oxyoke Canyon as the last quartzite bed, which usually forms one of the thicker quartzite beds in the member.

In the Desert Range, the Oxyoke Canyon becomes thicker with more abundant quartzite and weathers with a deeper rust color in contrast to similar rocks in the Sheep Range.

In the Sheep Range the thickness of the combined members is about 50 m. The unit was too thin to calculate a thickness from the map. The two members form an easily recognized map unit.

Upper Nevada Formation Undifferentiated (Dn). Above the Oxyoke Canyon-Beacon Peak lower unit, the remaining 195 m of the Nevada has no prominent lithologic breaks to provide further subdivision. The upper Nevada Formation is generally well bedded, often well laminated dolomite.

It frequently exhibits color banding, with black, white, and gray dolomite alternating on a scale of a few to tens of centimeters. Near the top of the Nevada a dense fossil bioherm is present, where a one to two meter thick zone of generally dark dolomite is crowded with the brachiopod *Stringocephalus*. Shells occur as closely packed cross sections in outcrop. Generally white in contrast to the matrix, the brachiopods cannot be readily removed from the rock. In the Desert Range and a few localities on the west side of the Sheep Range, the *Stringocephalus* occur in limestone rather than dolomite. Generally, however, the dolomite of the Nevada contrasts with the limestones of the overlying Devil's Gate limestone. Overlying the *Stringocephalus* zone, a thin sequence (10 m) of typical Nevada dolomites is present below the basal Devil's Gate.

In the badly brecciated terrain on the west side of the Sheep Range, at times the Oxyoke Canyon-Beacon Peak had to be lumped with the rest of the Nevada.

<u>Devil's Gate Limestone (Ddg)</u>. The Devil's Gate Limestone is 440 m thick and consists almost entirely of limestone, with a number of quartzite beds occurring in the middle part of the formation. The base of the formation is composed of an orange-weathering, silty dolomite that weathers to form a recessive slope above the Nevada Formation. The base of these silty rocks is taken as the base of the Devil's Gate. In places some transitional beds overlie the silty dolomite and resemble dolomite in the Nevada Formation, but generally limestone of the Devil's Gate lies directly above the silty dolomite. The Devil's Gate is thick-bedded, dark-gray to blue-gray limestone with coarse grain size.

The lowest part of the dark limestone contains no distinctive lithologic or sedimentary features and probably correlates with the Moapa Formation (Langenheim and others, 1962) in the Arrow Canyon Range. Abundant stromatoporoids are present higher in the Devil's Gate through approximately 100 m. The stromatoporoids resemble cabbage heads, frequently chertified and showing little detailed internal structure. "Spaghetti" corals occur less conspicuously with the stromatoporoids, along with rare crinoids columnals and horn corals.

Above the stromatoporoid-bearing beds is a sequence of limestone with numerous sandstone interbeds. These occur

as abrupt influxes of sand, bounded sharply above and below by limestone. Ryan and Langenheim (1973) measured nine sandstone intervals in the Arrow Canyon Formation (which also includes the stromatoporoids) of the Arrow Canyon Range and the eastern Las Vegas Range. About five thin sandstone beds less than a meter thick are present in the Sheep Range. The thickest sandstone, about 15 m thick and persistent through the Sheep Range, has been mapped separately as an informal quartzite member within the Devil's Gate. In part of the area west of Pine Nut Camp on the east side of the range, two sandstone bodies occur within the Devil's Gate. Neither the field relations nor the outcrop pattern suggest a fault, so that they are regarded as two separate sandstone bodies. Perhaps the second thick sandstone body is a channel that occurs locally within the Devil's Gate. Above the low-angle fault terrain on the west side of the Sheep Range, the thick sandstone bed can usually be located but is commonly sheared and tectonically thinned. In such badly brecciated areas, irregular bodies of quartzite and stromatoporoid-bearing limestone serve to identify the Devil's Gate from similar limestones of the Joana which contain crinoidal debris.

The remainder of the Devil's Gate above the quartzite-containing interval consists of pure limestone similar to that below the quartzites and interbedded with them.

Mississippian Formations

The Gass Peak thrust telescoped significant facies changes in the Mississippian rocks of the Cordilleran geosyncline. Longwell and others (1965) clearly noted this fact, by comparing the Mississippian of the Spotted and Sheep Ranges, which contain equivalents to the Pilot Shale, to the Las Vegas Range which does not. In the Las Vegas Range (Ebanks, 1965), Arrow Canyon Range (Langenheim and others, 1962), and the Spring Mountains (Burchfiel and others, 1974) Mississippian strata belong to the Monte Cristo Formation. In the Sheep Range the typical Monte Cristo members are not present. The presence of a basal clastic unit, the Pilot Shale, also emphasizes the difference. Mississippian rocks have been assigned to formations recognized in the region east of the Antler orogenic belt and to the north and west of the Sheep Range.

In the Spotted Range, Poole and Sandberg (1977) divided the Mississippian into four units: Narrow Canyon Limestone, Mercury Limestone, limestone of Timpi Canyon, and Chainman Shale. A long haitus underlies the Chainman, corresponding to the interval from middle Osagean to basal Chesterian. In contrast the Arrow Canyon section contains only two small hiatuses during the Mississippian, and the Pahranagat Range section records continuous deposition,

much of it terrigenous (Poole and Sandberg, 1977). Faunal evidence does not allow detailed determination of the Sheep Range depositional history, but a general similarity to the Spotted Range suggests that the Pilot Shale and Joana Limestone represent part of the Lower Mississippian and that the Indian Springs Formation belongs to the highest Upper Mississippian. A complete stratigraphic section through all three Mississippian formations is not present in the Sheep Range because of faulting.

Pilot Shale (Mp). The Pilot Shale in the Sheep Range corresponds lithologically with the Narrow Canyon Limestone of the Nevada Test Site or the Pilot Formation as used in the Pahranagat Range, although much thinner than either of those units. I prefer to call the rocks in the Sheep Range Pilot Shale, because the term has been widely used over much of Nevada and because the Narrow Canyon Limestone has not been critically evaluated since the pioneering reconnaissance of Johnson and Hibbard (1957).

The Pilot consists of less resistant, lighter colored rocks than the underlying Devil's Gate. Its abrupt contact with the Devil's Gate is marked by a thin (at most 2 m thick), laterally variable sandstone unit. This sandstone is pale pinkish, often has a calcereous matrix and crops out in well defined beds 10-15 cm thick. Above the sandstone

are dark, dense black chert and interbedded red shale. Like the sandstone, the chert is thin (1-2 m) but diagnostic. The bulk of the Pilot above the chert consists of platy, silty, light colored limestone that forms slopes.

The Pilot occurs in only two areas of the map area: the terrain above the the low-angle faults on the west side of the range, and on the east side of the range north of Pine Nut Camp. At Pine Nut, good exposures of the formation occur in low hills. In the low-angle fault terrain, the Pilot behaves as one of the weakest units and absorbs differential movement by brecciation, shearing, and folding, which severely affects the quality of the exposures.

Approximately 15 m of the Pilot are present in the Sheep Range, a thickness considerably less than the 107-122 m in the Desert and Spotted Ranges (Tschanz and Pampeyan, 1970).

Joana Limestone (Mj)

Limestones of the Joana resemble those of the Devil's Gate in their dark color and purity. However, the Joana can be clearly differentiated by: 1) an interval with abundant dark chert nodules which probably correlates with the Anchor Member of the Monte Cristo, and 2) abundant

fossils, especially crinoidal limestones.

The lower contact of the Joana is abrupt with dark limestone overlying silty limestone of the Pilot. The Joana contains both thin and thick bedded, generally dark limestone, with a thick horizon of very cherty limestone. The formation contains abundant fossils, especially crinoid columnals. Some of the round columnals contain a star-shpaed lumen, not seen in any other formation in the Sheep Range. Other fossils include brachiopods and corals, especially horn corals up to 10 cm long.

Internal stratigraphy of the Joana could not be satisfactorily resolved within the mapped area. On the east side of the Sheep Range in the southern part of the mapped area, the block of Joana rests in fault contact on the Devil's Gate. At this place the exposed sequence contains a dark, richly fossiliferous limestone at the base, overlain by a tan silty thin bedded limestone which here is crumpled and deformed. The next higher unit is a dark gray limestone, and the top of the exposed section is a medium gray to light yellow, cliff-forming limestone. Brachiopods, coiled molluscs, and very small crinoid columnals occur in the lowest unit. Near Pine Nut Camp, a depositional lower contact is present, but exposure is poor and I could not distinguish units within the formation that compared with those exposed in the Hoodoo Hills

Havoc on the west side of the Sheep Range. In the Hoodoo Hills Havoc, the Joana is involved in the extensive low-angle faulting and the stratigraphy could not be satisfactorily resolved.

Near Cow Camp Spring in the Havoc, Longwell (unpub. field notes, 16 May 1927) estimated the Mississippian rocks to be 225 m thick. Faulted against the Devonian he found, from bottom to top, 12 m of thin bedded shaly limestone [upper Pilot?]; 61 m of "heavy" limestone, massive with a basal buff-weathering zone; thin bedded limestone; 61 m of yellow, reddish, and rusty shale, [Indian Springs?]; and at the top, massive limestone, mainly dense and dark gray, 91 m. After mapping in the area where he estimated this section, I found exposures of the Joana to be badly faulted and his section could not be confirmed. In particular Longwell does not appear to have seen or attached any importance to the thick cherty zone. The second unit from the top of his section is probably the Indian Springs Formation, and I found no stratigraphic section that continued above those rocks. I suspect that Longwell's top unit represents fault repetition, with either lower Joana or Devil's Gate on top of the Indian Springs.

<u>Indian Springs Formation (Mis)</u>. The Indian Spring Formation can be widely recognized due to its distinctive red

shale chips and abundant goniatite ammonoids, even though it has the poorest exposures of any formation in Sheep Range. Neither the upper nor lower contact is exposed, and most outcrops are mostly covered by float. No rocks that belong to younger Paleozoic units are present in the Sheep Range. (Two possible exposures of Bird Spring or equivalent rocks may be incorporated in the low angle fault terrains, one in the Long Valley Block and the other in the Hidden Forest block.) The Indian Springs consists of shale, siltstone, and some sandstone with very small quartz pebbles. The formation is brightly colored red, yellow, and orange. These rusty colors predominate over lesser greens and tans.

The Indian Springs has a diagnostic Chesterian (highest Upper Mississippian) fauna, dominated by the goniatite <u>Richardsonites</u> <u>merriami</u> (Youngquist), formerly assigned to <u>Cravenoceras</u>. Other members of the fauna include the snail <u>Glabrocingulum</u> <u>quadrigatum</u> Sadlick and Nielsen, orbiculoid brachiopods, horn corals, pelycypods, and crionoid columnals. MacKenzie Gordon, Jr. (pers. comm., 1979) identified the fossils.

The Indian Springs also contains fossils of land plants, less widely distributed than the animals. S. Mamay (pers. comm., 1978) examined some fragmentary material and indicated they were Carboniferous in age. A tentative

determination of Calamites suggested a lower Pennsylvanian age, but the preservation was such that the plants might be Mesocalamites, which has a range from the Upper Mississippain to the Lower Pennsylvanian.

Webster and Lane (1967) restricted the Indian Springs and raised it to formational rank, rather than regarding it as the basal member of the Bird Spring as initially proposed (Longwell and Dunbar, 1936). Webster (1969) measured three sections in the Las Vegas Range, all in the lower plate of the Gass Peak thrust and tectonically distrubed.

Bird Spring Formation (PPbs). The Bird Spring Formation is present in the lower plate of the Gass Peak thrust, and only the rocks of the Bird Spring directly below the trace of the fault contact and on two traverses down the face of the Las Vegas Range were mapped in this study. These rocks yield fossils which indicate Permian ages probably belonging to the upper part of the Bird Spring. Ebanks (1965) identified Pseudofusulina of Leonard age from the Bird Spring on Gass Peak. Vincelette (1964) found Permian Schwagerina near the Wheeler Pass thrust contact. Ebanks (1965) found 1676 m of Bird Spring within the Gass Peak quadrangle, compared to the estimate of 1524 m for the Wheeler Pass area (Vincelette, 1964). Welsh (1959) measured a section within the Las Vegas Range and the area

mapped by Ebanks, finding 837 m of Permian Apex Formation and 943 m of Pennsylvanian Bird Spring. Since later workers have not accepted the Apex as a valid unit, a thickness of 1780 m is accepted for the Bird Spring in the Las Vegas Range.

The Langenheims (1965) proposed treating the Bird Spring as a group with five formations. Lithologic correlation and subdivision within the Bird Spring cannot presently be made except for the two basal formations. The Battleship Wash Formation (Langenheim and Langenheim, 1965; the Bsa unit of Langenheim and others, 1962) does not extend to the Sheep Range. The Bsb unit of the Arrow Canyon Range correlates with the Indian Springs Formation, which is present in Sheep Range as the highest exposed unit. Webster (1969) noted that Langenheim and Langenheim's unnamed formations Bsc to Bse could only be recognized with difficulty at Arrow Canyon, and suggested that group status for the Bird Spring was not warranted. No mapping work to date has successively subdivided the Bird Spring above the Indian Springs, and it is here treated as a single, thick formation.

Beneath the Gass Peak thrust, the Bird Spring consists of light gray limestone with chert, silt, and sandy interbeds. The formation contains abundant fossils with fusulinids, brachiopods, coiled cephalopods, gastropods, crinoids, trilobites, and corals most common. Abundant "rice grains"

make much of the Bird Spring a fusulinid limestone, and make it impossible to cross the Gass Peak thrust without rapidly recognizing lower plate rocks. A trilobite pygidium in the Bird Spring east of Wamp Spring was identified as Ditomopyge cf decurtata (Grabau) by C.C. Chamberlain (pers. comm., 1977).

Near Wamp Spring, the Bird Spring is cut by a complex schuppen zone just below the Gass Peak thrust. Fusulinids occur within 5 m of the thrust contact, but show little or no finite straining.

Breccia of Paleozoic rocks (Pzb). This map unit consists of brecciated and recemented Paleozoic rocks. The time of brecciation and deformation is assumed to be Tertiary. The unit occurs in two areas. The first is on the west side of the Sheep Range, on the extreme northern edge of the mapped area where a small mass of brecciated Paleozoic rocks occurs. It consists of brecciated Eureka, Ely Springs, Laketown, and Nevada formations, which occur in proper stratigraphic order with the Eureka to the west and successively younger units to the east but too thin and too badly brecciated to map individually. The outcrop bands strike generally northward. The second area of breccia is at Hidden Forest. Much of this unit is overgrown by ponderosa pine forest, which obscures contacts and outcrops.

I interpreted the region in Hidden Forest as a slide block obscured by vegetation. The bulk of the Hidden Forest block appears to consist of Devonian and Mississippian limestones like the Long Valley block (see below) although the Hidden Forest block may contain significant amounts of Nevada Formation dolomite. Ordovician rocks may represent bedrock exposed in windows through the slide block. The Hidden Forest area contains a complex pattern of faults, evident on the geologic map (Plate I) and poor outcrop precluded more detailed mapping of the Hidden Forest block. This terrane has been designated only as Paleozoic breccia with the understanding that most of the breccia is transported Devonian and Mississippian formations above brecciated Ordovician that could be in place.

Mississippian and Devonian Carbonate Rocks (MDc). This map unit was reserved for brecciated limestone that could not be confidently assigned to either the Joana or Devil's Gate limestone. The limestone content, dark color, and tendency to form cliffs distinguish these formations from all others in the Sheep Range. When brecciated, however, the two can be difficult to distinguish from one another. Where possible, the brecciated limestone was mapped with the formation to which it belonged. This map unit was used for two cases: 1) when diagnostic features were absent

(such as quartzite or stromatoporoids for the Devil's Gate, or chert and crinoidal limestone for the Joana, or 2) when the two formations appeared intimately mixed. Minor amounts of the Nevada Formation might be included in this map unit in a few places, but generally this unit represents only the upper Devonian and Mississippian. Characteristic Bird Spring lithologies or fossils are not present in this unit. Brecciation and recementation probably occurred during the Tertiary (see below).

Horse Spring Formation (Ths). The term Horse Spring Formation covers a wide range of stratigraphic ignorance in southern Nevada. Current work should help redefine the Horse Spring, and restrict it to a sedimentary basin developed between 18 m.y. and 10 m.y. (Bohannon, 1979a, b). If this revision of the type section becomes accepted, some deposits mapped as Horse Springs may belong to older basins that contain similar conglomerates and tuffs. Examples are the 29 m.y. K/Ar ages cited by Hinrichs (1968) and Marvin and others (1970) for Horse Spring deposits in the Nevada Test Site. These are much older than rocks assigned by Bohannon to the Horse Spring (17.4 - 10.6 m.y. B.P.) or by Anderson and others (1972), who gave an age range of 21.3 - 13.2 m.y. B. P. for similar rocks.

Based on radiometric dating, the rocks in the Sheep

and Las Vegas Ranges assigned to the Horse Spring appear to correlate with the lower clastic unit of Bohannon (1979a, b). Although unreported in his thesis, Ebanks obtained K/Ar ages of 15.2 and 15.9 m.y.B.P. on biotite from volcanic tuff exposed between Gass Peak and Fossil Ridge (J.F. Sutter, pers. comm. to Ebanks, 1968). Ebanks also reports ostracods from his Horse Spring Formation, which F.M. Swain (pers. comm. to Ebanks, 1965) tentatively suggested as Oligocene to Miocene in age.

Rocks mapped in the Sheep and Las Vegas Ranges as Horse Spring have not yet been dated. Fossiliferous limestones collected in the Black Hills and near Rye Patch Spring failed to yield diagnostic ostracods, diatoms, or other fossils. Radiometric dating of volcanic tuffs has not been completed.

In the Sheep Range, the Horse Spring rests with angular unconformity on various Paleozoic formations. Its importance in timing relationships for the faulting will be discussed later. The bulk of the formation consists of conglomerate composed exclusively of locally derived sedimentary rocks. Carbonate rocks form most of the clasts, and the clasts can be identified as coming from the Pogonip, Nevada, Devil's Gate, and Joana formations. Bird Spring clasts could not be recognized, suggesting that even in the Wamp Spring area the direction of transport was from the Sheep

Range toward the east. Sediments from the Eocambrian clastic wedge were also not recognized in the Horse Spring. Quartzite clasts represent such local units as the Eureka and the quartzite from the Devil's Gate. Most clasts are rounded to subrounded, with much of the conglomerate clast-supported with matrix in filling. Near Wamp Spring clasts up to 45 cm in diameter are present. No plutonic, metamorphic, or volcanic clasts occur. Subordinate lithologies in the Horse Spring include volcanic tuff with fresh biotite flakes, sandstone beds representing channel fill, siltstone, and limy marl.

At least 100 m of Horse Spring is present in the vicinity of Wamp Spring. With the variable lithology and limited outcrop, no attempt was made to describe a detailed stratigraphic section. In areas of poor exposure, the Horse Spring can easily be confused with recent alluvium which contains clasts of the same units in the same state of rounding. On the west side of the Sheep Range, this problem is especially severe; much of the area mapped as alluvium between Wildhorse Pass and the north edge of the map could be underlain by extensive Horse Spring deposits which are weathered and eroded in place to resemble alluvium. Areas mapped as Horse Spring consist of well-cemented, bedded conglomerates or sandstone, siltstone, limestone, or volcanic tuff. Only the tuffs weather distinctively

and are different than the alluvium.

Quarternary Alluvium (Qal)

In the bottom of all washes and in the fans and valleys separating the ranges, angular to rounded boulders, cobbles, pebbles, and sand constitute the alluvium. In places this can be difficult to separate from the Horse Spring, as noted above. In some of the deeper washes older and cemented alluvium can be detected. Older alluvium was not mapped separatedly, as it occurs only in areas such as Yucca Forest which were not mapped in detail.

CHAPTER III. DESCRIPTIVE STRUCTURAL GEOLOGY

Discussion of the structural geology will be divided into two parts: first, a description of field relationships and observations of the structure in the mapped area, and second, an interpretation of the data and examination of its regional significance.

Description of Structural Relations

One of the major structures in the area is the Gass Peak thrust whose trace trends north-south near the eastern edge of the mapped area. Beneath the thrust, the limestone of the Bird Spring Formation has been overturned eastward in a syncline which has been locally faulted along its axial plane. Rocks of the Eocambrian clastic wedge lie above the thrust and generally dip to the west. They have been deformed in a complex schuppen zone, above which the carbonate rocks of the Bonanza King Formation are relatively undeformed and essentially subhorizontal.

The easternmost high-angle fault of large displacement in the Sheep Range, the Mormon Pass fault, downdrops rocks on the west and rotates eastward all the strata in the range. All fault blocks to the west of the Mormon Pass fault contain Paleozoic units that dip to the east. The

faults characteristically drop the west side.

Two major low-angle fault blocks, the Hidden Forest block and the Long Valley block, lie near the crest of the Sheep Range. The faults at the base of these blocks place younger rocks on older, and rocks in the hanging wall dip more steeply than rocks in the footwall.

On the west side of the range, the Wildhorse Pass fault separates a homoclinal western part of the Sheep Range from the Hoodoo Hills Havoc. The Havoc consists of a complex arrangement of fault blocks and slivers, and contains both low-angle and high-angle faults. The Havoc extends to the eastern margin of the Black Hills. Most of the low-angle faults in the Havoc place older rocks on younger. Rocks in the Havoc have been deformed, with the dolomites intensely brecciated whereas the limestones remain relatively more coherent.

The Black Hills contains two fault blocks of coherent Cambrian and Ordovician rocks, disrupted by minor high-angle faults. The mapped portion of the Desert Range contains two major north-south faults, one repeats units and the other omits units. Minor hanging wall remnants of a low-angle fault are present on two ridges.

Excluding the disrupted fault blocks in the Hoodoo Hills Havoc, the units across the map show a progressive rotation of bedding. Along the crest of the Las Vegas

Range, beds in the upper plate of the Gass Peak thrust dip moderately steeply (40-60°) to the west. Approaching the Mormon Pass fault, their dips decrease to sub-horizontal. In the Sheep Range, beds dip an average of 20-30° east; in the Black Hills about 40° east; and in the Desert Range the average dip increases to 50° east.

Gass Peak Thrust Fault

Two areas along the crest of the Las Vegas Range expose the trace of the Gass Peak thrust. In the southern part of the area mapped, the continuation of the Gass Peak thrust trace, as mapped by Ebanks (1965), is present below Quartzite Mountain. In the northern part of the mapped area near Wamp Spring additional exposures of the thrust are present before it disappears under alluvium.

The actual thrust surface is not exposed in either area. Upper plate quartzites of the Wood Canyon or Stirling generally crop out within several meters of lower plate Bird Spring limestone. Thus, at the map scale the thrust fault could be easily located without ever finding an actual exposure of the fault.

Rocks near the thrust fault are brecciated for perhaps several meters.

Both upper and lower plates of the Gass Peak thrust

contain imbricated thrust slices. The schuppen zone of the upper plate crops out poorly, although exposures near Quartzite Mountain and Wamp Spring clearly reveal the nature of the zone. Upper plate deformation appears limited to the Carrara Formation and lower units, and consists of large scale slices and smaller structures such as folds and the development of slaty cleavage (Figures 6,7). Within the Bird Spring of the lower plate, anastamosing lenses of small size (tens of centimeters) are bounded by faults subparallel to the thrust (Figures 8,9). Due to limited study of the lower plate, the extent of this type of deformation was not established.

Folding accompanied deformation in both plates. Along much of the trace of the thrust the Bird Spring in the lower plate forms a tight, eastward-overturned syncline that appears locally to be faulted along its axial surface. Within the upper plate, near Quartzite Mountain, a ramp anticline occurs along with several broad open folds in the Bonanza King Formation. Near Wamp Spring the Carrara Formation contains very small scale upright isoclinal folds in thin limestone beds within shale. Fold axes plunge gently northward (Figure 6).

The stratigraphic displacement on the Gass Peak thrust is calculated to be approximately 5900 m, using the thickness given in Table 1. This figure assumes the thickness of

Figure 6. Isoclinal Folds in Carrara Formation.

These folds occur in a thin limestone interbed within a thick shale sequence. The folds trend north and plunge gently north, 16°. The folds occur northwest of Wamp Spring. East is to the right of the photograph.

Figure 7. Slaty Cleavage in Carrara Formation.

Slaty cleavage in the Carrara Formation [illegible] rarely this well developed. This outcrop is on the west side of Quartzite Mountain, on the east limb of the ramp anticline. Bedding strikes N35E and dips 10° SE, and cleavage strikes N[illegible]W and dips 20° W.

Figure 8. Bird Spring Formation Beneath Gass Peak Thrust.

This shear zone occurs just east of Wamp Spring in Bird Spring limestone below the Gass Peak thrust. East is to the right, and the fault slices merge with a higher subhorizontal fault surface which is out of view. Hammer in lower left of photograph gives the scale. Limestones within this zone yield fusulinids which appear unstrained.

Figure 9. Lower Plate Slicing near Quartzite Mountain.

These Bird Spring Formation limestones appear in the first outcrops below the float zone marking the Gass Peak thrust on the east side of Quartzite Mountain.

Figure 6.

Figure 7.

Figure 8.

Figure 9.

4105 m for units in the upper plate from Stirling Quartzite to Indian Springs Formation, and assumes that the 1780 m thickness of Bird Spring exposed in the lower plate belongs atop the section in the upper plate. This compares with the 5486 m cited by Ebanks (1965).

Horizontal displacement on the thrust cannot be estimated with the information obtained during this study, and estimates of horizontal displacement are discussed below.

Detachment within the upper plate did not follow a single stratigraphic horizon. Either the Stirling Quartzite or the Wood Canyon Formation appears at the base of the thrust plate. Within these rocks no single stratigraphic horizon serves as a detachment surface. The schuppen structure of the upper plate determi. which formation occurs in the slice at the base of the Gass Peak plate.

The lower plate and its complicated Bird Spring stratigraphy did not receive sufficient attention to determine the level at which the thrust occurs. Nevertheless the Gass Peak thrust appears everywhere to cut nearly the same horizon. The generally flat outcrop of the Bird Spring away from the thrust, the topographic expression of the ridge forming the crest of the Las Vegas Range, and the lack of east-west structures below the thrust all support the interpretation that the thrust cuts nearly the same

stratigraphic horizon in the Bird Spring along strike.

<u>Quartzite Mountain Thrust Exposures.</u> Quartzite Mountain is underlain by a large thrust slice of complexly interleaved rock units. This feature is clearly reflected on the geologic map in the wide variety of measured attitudes. The bulk of the mountain consists of Stirling Quartzite, in places showing highly polished and slickensided surfaces. Rocks assigned to the Wood Canyon Formation also crop out, suggesting that the slice contains internal structure which could not be mapped because of poor exposures. Locally, the Carrara Formation occurs in this slice, as distinctive orange-weathering Carrara limestone attracted prospectors who dug a test pit on the southeastern flank of Quartzite Mountain. Contacts and fault boundaries within this major slice on Quartzite Mountain could not be mapped because of scale and poor outcrop, and the entire slice has been mapped as Stirling. The relief on the lower contact of the slice allowed determination of the dip on the thrust by geometric construction of a three point plane, which yielded a fault plane dipping about 10° to the west.

To the west of Quartzite Mountain, an anticline overrides the slice (south of section E-E' Plate II). Poorly exposed Wood Canyon Formation forms the core of the anticline, which plunges northward where only the Carrara

Formation crops out. Carrara on the eastern limb of the anticline occurs in thrust juxtaposition with the Stirling on Quartzite Mountain at the southern edge of the mapped area. Northward the Quartzite Mountain slice disappears and a syncline appears to the east of the anticline. Wood Canyon then forms the base of the upper plate, as in section E-E'. To the north of the section, the folds die out and the upper plate consists of a normal west dipping section beginning with the Wood Canyon.

To the west, several broad open folds occur on the east side of Peek-a-boo Canyon. These are gentle warps in the Bonanza King Formation which here dips 10-20° to the west. The folds occur in the basal silty unit of the Banded Mountain Member, and the reddish silty beds of this unit serve to highlight the folds. The upright folds trend to the north.

Wamp Spring Thrust Exposures. In the vicinity of Wamp Spring, the trace of the Gass Peak thrust crops out for 3 km. The Paleozoic rocks appear exposed along an exhumed erosional surface, as the adjacent ridges have caps of Horse Spring conglomerates. At the north end of the Paleozoic outcrops, the thrust is unconformably overlapped by the Horse Spring. Farther north the trace of the thrust cannot be located because it underlies Quaternary alluvium. The Wamp Spring

exposure constitutes the only direct evidence for an upper age limit to movement on the Gass Peak thrust which must have ceased motion before Horse Spring deposition.

The deep canyon cut through lower plate rocks just east of Wamp Spring clearly exposes structural details in the lower plate. To the east where the crest of the Las Vegas Range dies into low hills, the Bird Spring dips gently to the west. The west side of the main ridge of the Las Vegas Range contains very steep dips toward the west, which are probably overturned. They make a sharp contact with the much more shallowly dipping beds, a contact marked by a cliff on either side of the canyon. The cliff marks the sheared rocks along the axial surface of the overturned syncline.

About 2 km south of this canyon, exposures on the crest of the Las Vegas Range also show similar relations in the lower plate (section A-A'). On the east side of the range, the Bird Spring dips very gently toward the west. Within a short distance near the crest of the range, beds dip vertically and then steeply toward the west. These beds are probably overturned, but the lack of facing indicators in the Bird Spring does not allow verification of this interpretation.

Small scale structures within lower plate rocks also occur in the Wamp Spring area. On the east face of the

cliffs below the faulted synclinal axis, thin bedded limestones are crumpled and folded. In outcrops directly below the thrust fault on the west side of the drainage near Wamp Spring s small scale schuppen zone is exposed (Figure 8). Many small faults merge with sub-horizontal master surfaces above and below the zone of slicing. The sense of shear motion clearly indicates transport toward the east.

Within upper plate rocks, stratigraphic repetition indicates significant slicing and imbrication. The alternation of rocks assigned to the Stirling and Wood Canyon in contact with the Bird Spring clearly demonstrates that the Gass Peak thrust does not follow a single stratigraphic horizon over even a short distance. Furthermore, on the ridge to the south of Wamp Spring low-angle faults separating relatively unsheared rocks are clearly exposed. In the most unequivocal example, a thin sliver of the Carrara Formation rests depositionally atop the Wood Canyon. In thrust contact above the Carrara are quartz pebble conglomerates of the Stirling, overlain by Wood Canyon and Carrara in normal stratigraphic sequence. Both the Carrara and Stirling outcrops can be traced laterally before being cut off by the thrust, which then continues within the Wood Canyon Formation. The thrust climbs section to the north where it separates the Carrara and Wood Canyon and cuts

out the thin unit correlated with the Zabriskie Quartzite. Other slices in the Wamp Spring area can be recognized by the inversion of the sequence between the Stirling quartz pebble conglomerates and Wood Canyon exposures, and by brecciated fault zones exposed in the two shafts on the ridge north of the spring and in the mine tunnel immediately to the north.

Additional imbrication within the Carrara can be inferred, based on the exposed outcrop width of the formation (section A-A'). Individual faults could not be located, but the shale of the Carrara shows widespread slaty cleavage that cannot be related to any observed pattern of larger scale structures. Thin limestone units within the shales show isoclinal folding, oriented north-south and plunging 16° to the north (Figure 6).

Slickensides on imbricate faults in the Wamp Spring area suggest the orientation of displacement on the Gass Peak thrust. Two measurements in the sliver of Stirling that occurs at the base of the upper plate showed slickensides oriented S57W plunging 46° and S65W plunging 63°. A reading in the Bird Spring on the western side of hill 6087 showed slickensides oriented S80W and plunging 46°, and a reading in the Bird Spring on the ridge just east of Wamp Spring gave an orientation of S80W plunging 50°. This data suggests a relatively eastward transport of the

upper plate rocks.

Low-Angle Faults

A terrain cut by numerous low-angle faults and lying above rocks relatively undisturbed is present throughout a large part of the western half of the map area (Figure 10). In the Sheep Range low-angle fault blocks are present as two large masses, the Hidden Forest block and the Long Valley block, and as several smaller, scattered blocks. On the west side of the Sheep Range, a low-angle fault complex, informally referred to as the Hoodoo Hills Havoc, is present between the homoclinal Sheep Range sequence and the Black Hills. The Havoc lies to the west of Joe May Canyon and the Wildhorse Pass fault, and incluc the low hills between Cow Camp and Black Hills Gap. The bulk of the low-angle fault terrain consists of Devonian and Mississippian rocks, but to the north the Havoc also contains extensive Ordovician and Silurian rocks.

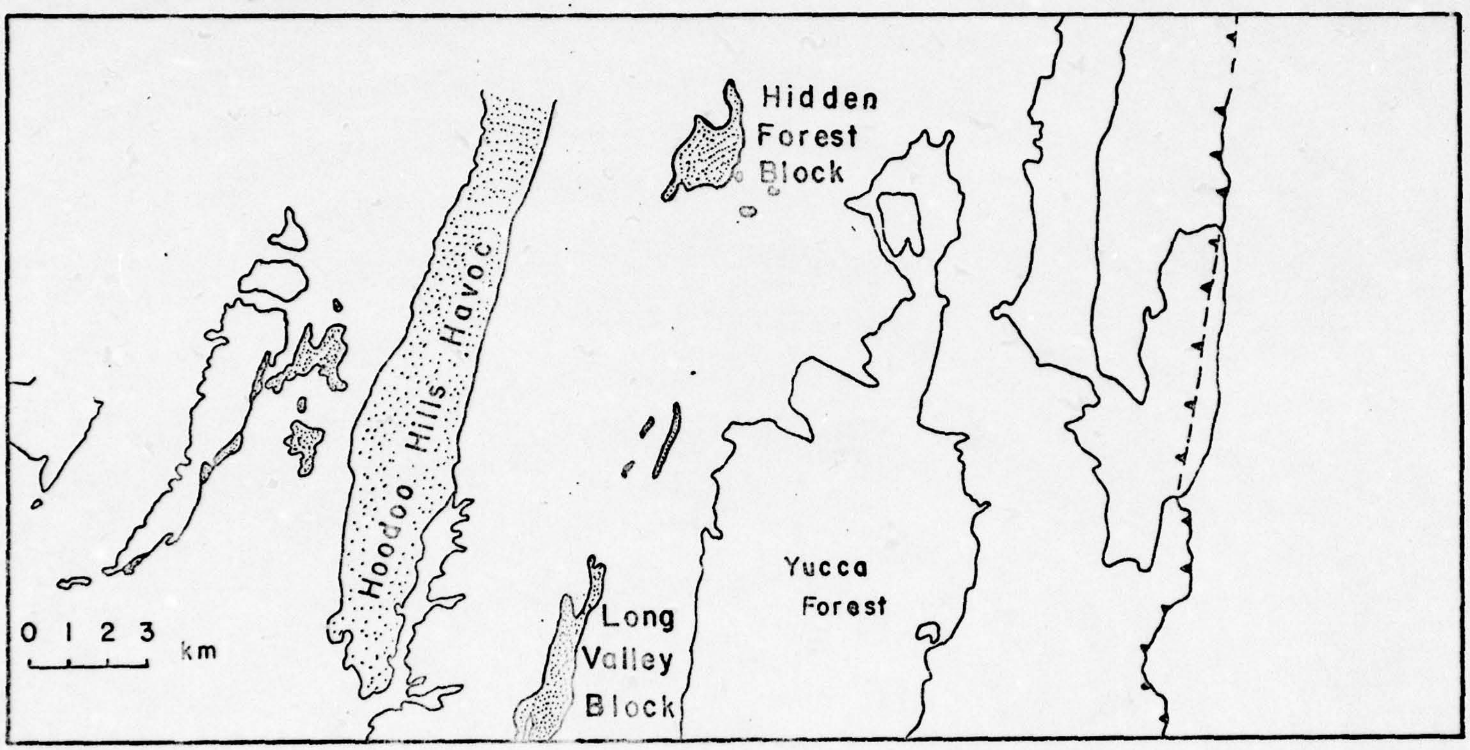
The low-angle terrain exhibits extremely brittle deformation, with almost complete brecciation of dolomites of the Nevada or Ely Springs formations. These units now contain angular clasts of dolomite in a recemented matrix, and can only recognized by gross color and lithologic similarities with the undeformed formation. Limestone tends

Figure 10. Location of Low-Angle Fault Blocks.

All low-angle fault terranes in the Sheep Range are indicated on this figure. The named blocks are shown, as well as the locations of the other blocks. At least seven blocks must be present: two atop the Sheep Range, the Long Valley and Hidden Forest blocks; at least three major blocks in the main part of the Hoodoo Hills Havoc; and two blocks in the low hills east of the Black Hills. Other blocks may correlate with these, or could represent separate blocks. The blocks on the east side of the Black Hills must represent either a later episode of low-angle faults or landslides.

Figure 10.

Low-Angle Fault Terranes in the Sheep Range



to be less brecciated and usually maintains bedding that contains broadly consistent but disrupted attitudes. Quartzite and shaley interbeds within the limestone, such as the Pilot Shale or the quartzites within the Devil's Gate are strongly brecciated and disrupted. Motion and slip within the low-angle blocks appear to have been preferentially along the clastic interbeds which are intensively sheared and locally faulted. The clastic beds can be traced along strike only with difficulty, and they exhibit changes in thickness and locally are faulted out and absent. Frequently the clastic units could not be mapped separately.

The low-angle terrains exhibit a characteristic outcrop pattern recognizable from a distance. They form ledgy, rounded cliffs that lack obvious bedding. Bedding may be present especially in the limestones, but from a distance it appears to be either absent or diffuse.

<u>Long Valley Block</u>. The Long Valley block extends for 5 km along the crest of the Sheep Range and continues an unknown distance to the south into the Corn Creek Spring quadrangle (Figure 11). This block consists entirely of the upper limestone part of the Paleozoic section exposed in the Sheep Range, with the Devil's Gate and the Joana Limestone forming the bulk of the block. Smeared-out thin outcrops

Figure 11. Long Valley Block.

View south along the western margin of the Long Valley block. The ledge is formed by the Devil's Gate Limestone in the hanging wall, and the talus slopes below belong to the Nevada Formation in the footwall.

Figure 12. Hidden Forest Block.

Prominent cliffy exposures of the Hidden Forest block, which are probably largely of the Devil's Gate and Joana Limestones. This exposure occurs on the north side of the Hidden Forest road on the west margin of the block.

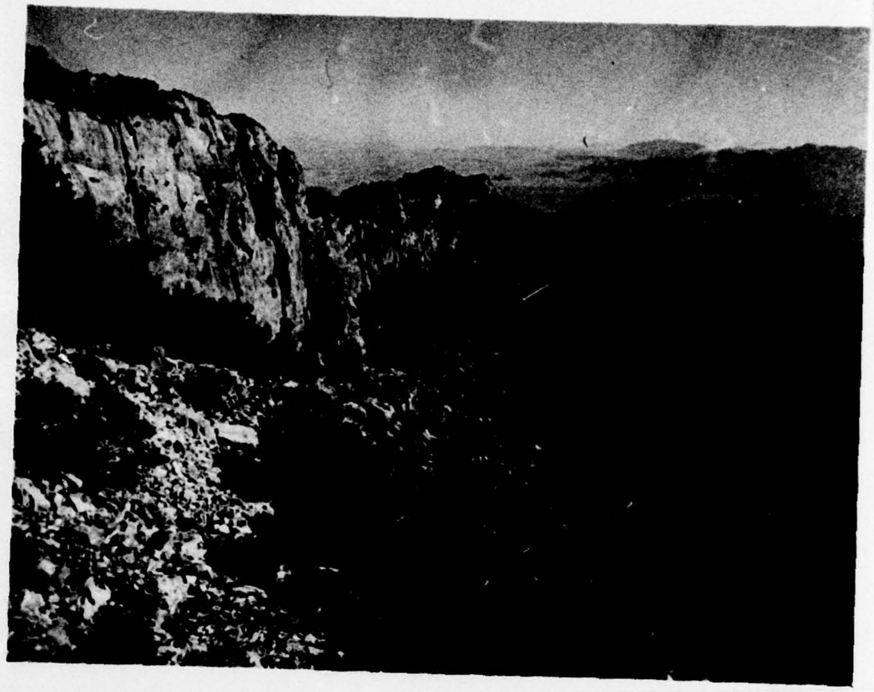


Figure 11.

Figure 12.

of the Devil's Gate quartzite unit, the Pilot Shale, and the Indian Springs Formation occur within the block. One small outcrop of shattered Nevada dolomite is present, and could mark either an important higher fault slice or a small sliver incorporated in the block. Repetition of units clearly indicates internal faulting within the block that has imbricated the rocks and that rotation along high-angle faults within the block repeats the section of Devil's Gate and Joana Limestones. Both types of relations can be demonstrated. Two small fault blocks of the Devil's Gate to the west of the large block presumably represent outliers of a once larger block.

Units within the Long Valley block share the regional north strike of the entire range, but dips within the block show significant steepening. Bedding in the units below the low-angle fault block generally dips shallowly toward the east, except at the southern edge of the map area where they dip to the west forming part of a large syncline (section E-E'). This fold is better developed to the south of the map area, and can be clearly seen from Las Vegas Valley. Below the Long Valley block, dips rarely exceed 20°, while within the block the dips range from 50° to 80°.

The contact of the Long Valley block with the underlying Nevada Formation is sharp, with brecciation of the underlying dolomite extending downward for only a few meters

below the fault. The fault surface is not well exposured and determination of its attitude is difficult because the disrupted limestone in the block forms a resistant ledge whose talus obscures the contact. The block stands out from a distance, with typically irregular cliffs that reflect the disruption of bedding (Figure 11). Several such cliffy ridges are present within the block as well as along its western margin.

Four fault planes within the southern part of the block allowed measurement of the fault's dip. All presently dip toward the east or the southeast, with measured dips of 18°, 30°, 43°, and 75°. The range of dips suggests several families of faults, both high and low-angle, are present in the Long Valley block. Geometric considerations also require both types of faulting. A high-angle fault must underlie (and may cut) the Long Valley block, because of the difference in elevation of the Oxyoke Canyon-Beacon Peak members on the west side of the Sheep Range and on the east side of Long Valley. The exposure of the Long Valley block, largely on the crest of the range and on the dip slope on its east side, strongly suggests a very shallowly dipping fault contact under the block. The window through the fault block also suggests that its basal contact is a low-angle fault.

Much of the Long Valley block contains readily

recognized although disrupted sedimentary bedding, although parts contain thoroughly brecciated limestone. To a large degree the brecciation increases in the northeastern part of the block, where several traverses failed to locate measureable bedding attitudes.

Cross section E-E' goes through the Long Valley Block, and clearly reveals that the block is very thin and bounded by a basal low-angle fault.

Brecciated Slivers Northeast of the Long Valley Block. Northeast of the Long Valley block and along structural strike lie two belts of brecciated limestone. These consist of thoroughly brecciated limestone, which locally contains stromatoporoid heads and thus must include some Devil's Gate Limestone, although some rocks may belong to the Joana. The two belts lie on the dip slope in fairly dense ponderosa pine forest, and outcrop cannot easily resolve their precise structural position. They definitely form fault slivers, and both lie along the trace of north-south normal falts which display west side down relationships. These slivers appear on cross section D-D'.

Two possible interpretations are possible for the brecciated limestone slivers. First, the breccias could be related to and follow a high-angle fault zone. However they should have come from well above the erosion level on

either side of the fault, and it seems difficult to tectonically drop the breccias down into a normal fault zone. Alternatively the slivers could represent remnants of a once more extensive low-angle fault block, probably the Long Valley block. Both rest on beds low in the Nevada Formation above the Oxyoke Canyon Sandstone, a situation similar to the Long Valley block, and contain the same rocks. In this interpretation the slivers are erosional remnants preserved on the downthrown side of a normal fault with the normal fault forming their east side and a poorly preserved low angle fault contact forming their west side.

If these slivers belong to the Long Valley block, it originally extended at least 9.6 km along the crest of the Sheep Range. Any extension of the block to the north has been eroded, and it has an unknown additional length to the south where it has not been mapped.

Hidden Forest Block. The Hidden Forest block covers an area of about 2 x 3 km between the crest of the Sheep Range and Hidden Forest Ridge (see Figure 12). The entire block lies above 8000 feet in heavily forested terrain, largely ponderosa pines, and has some of the poorest exposure in the Sheep Range. Rocks within the block are clearly out of place. Rocks of the Devil's Gate and

Joana Formations predominate. Stringocephalus-bearing Nevada dolomite and possible productid brachiopod-bearing limestone that could have been derived from the Bird Spring are present. Ordovician and Silurian rocks could be involved but they have not been positively identified within the block.

Obvious cliffy outcrops form two ridges north of the Hidden Forest Road (Figure 12). These resemble cliffy ridges in the Long Valley block or the Hoodoo Hills Havoc, showing the characteristic hummocky appearance of brecciated and disrupted bedding.

Bedding has been so completely disrupted that combined with the poor outcrop I could not measure any attitudes. Initially the block was mapped as a landslide with no coherent internal structure.

Reexamination of the Hidden Forest block after recognition of low-angle fault terrains in the Sheep Range suggests that similar relations exist under the pines, but that outcrop control does not permit the detailed mapping possible in the Long Valley block. Small outcrops of the underlying Ordovician units appear below the block as windows, one of which is mapped in the center of the block. These windows suggest that high-angle faults have displaced the block. The Hidden Forest area contains a very complex pattern of faults, as shown on the geologic map.

Blocks Southeast of Hidden Forest. Two blocks of brecciated Devil's Gate Limestone, recognized from the presence of stromatoporoids and characteristic quartzite beds, occur near the top of the Sheep Range to the southeast of Hidden Forest. Both occur on small areas of relatively level ground. One lies mostly on the Ely Spring Dolomite, but laps onto the Laketown and the Eureka. The other overlaps a fault separating the Ely Springs from the Aysees Member of the Antelope Valley. These may be remnants of the Hidden Forest block, or separate blocks or landslides that overlie higher stratigraphic units than the Hidden Forest block.

Hoodoo Hills Havoc. A low-angle fault terrain extends for at least 16 km along the west side of the Sheep Range. The southernmost exposures occur at the mouth of Joe May conyon near the southern edge of the mapped area. The Havoc extends beyond the northern edge of the mapped area. The informal name for the terrain comes from Longwell's observations (Unpublished field notes, 16 May 1927) that the rocks were tectonites that eroded to form hoodoos (Figure 13, 14). Dolomite, especially the Ely Springs, has been thoroughly shattered and then recemented. The dolomite weathers to form cones without discrete caps. The hoodoos are characteristic of the Hoodoo Hills Havoc,

Figure 13. Hoodoos in Joe May Canyon.

These hoodoos occur in Joe May Canyon on the southwest side of hill 6895. Rocks involved in this area belong to the Nevada Formation, and represent characteristic outcrop in the eastern part of the Hoodoo Hills Havoc.

Figure 14. Hoodoos near Rye Patch Spring.

These hoodoos occur to the north of Rye Patch spring on the southeast side of hill 6945, and involve largely Nevada Formation dolomite. Brecciation is extremely intensive, and other dolomitic units could also be present. This is probably the area where Longwell described the dolomitic outcrops as hoodoos in his field notes, and is the best development of the feature in the Hoodoo Hills Havoc. See figure 17 for a closeup of the black on white fault surface.

which also contains breccia ridges similar to those in the other slide blocks.

I use the term Hoodoo Hills Havoc guardedly, and only as the name of a specific structural terrain. It is a non-genetic term and shorthand referring to a thoroughly faulted and disrupted terrain.

The Hoodoo Hills Havoc extends between the Black Hills on the west and the base of the Sheep Range proper on the east. Joe May Canyon and the trace of the high-angle Wildhorse Pass fault mark the base of the faulted homocline that underlies most of the Sheep Range. Topography on the eastern side of the Havoc is generally rolling and subdued, whereas the Sheep Range has steep slopes leading to the crest of the range.

Within the Hoodoo Hills Havoc, all rocks show some degree of brecciation and disruption. I was unable to locate a basal slide surface beneath which the rocks were structurally in place and undisturbed, although the cliffs near Cow Camp could represent such a section continuous downward as suggested in section D-D'.

Rocks involved in the Havoc range in age from Ordovician (Antelope Valley Limestone) to highest Missisiippain (Indian Springs Formation). In general the youngest rocks crop out at the southern end of the area, whereas progressively older rocks appear to the north. This accounts

Figure 13.

Figure 14.

for the inability to define the limits of the terrain northward because Cambrian and Ordovician rocks in the Hoodoo Hills Havoc merge with rocks of the same age in the East Desert Range and the Sheep Range. Since Longwell and others (1965) did not clearly recognize or map the Havoc, their map cannot be used to distinguish the Havoc when it juxtaposed similar rocks.

The Havoc occurs in two settings: 1) in the belt on the west side of the Sheep Range and 2) in the low hills between the Sheep Range and the Black Hills. The exposures in the low hills extend onto the eastern side of the Black Hills.

The quality of outcrop in the Hoodoo Hills varies with the lithology and position. Limestone at the top of the Paleozoic section that belongs to the Devil's Gate and the Joana formations, tends to form massive cliffs whether it has been brecciated or has remained relatively coherent. The limestone frequently retains bedding and assignment to a given formation is clear. The lower dolomitic units tend to become more thoroughly brecciated. Bedding in the dolomite frequently is absent, and formation assignment can be made with difficulty and only by gross color or lithology. The dolomite also weathers to form hoodoos or areas of rolling, rounded hills with much poorer

exposures than the limestone. Since dolomite dominates the northern and eastern parts of the Havoc, these areas have poorer exposures than rocks at the southern end which are dominantly limestone. The Nevada Formation, the unit just below the limestones, can weather in places to form rugged outcrops similar to the overlying limestone. Elsewhere, the Nevada resembles the poor outcrop of the Laketown and Ely Springs Dolomites. Thicknesses of the units vary greatly, as does the ease of identifying formations. The map of the Havoc thus represents a generalization of a terrane of great complexity.

The poor outcrop of some units masks important structural relations. In particular the thickness of the Oxyoke Canyon-Beacon Peak members in some areas, such as the vicinity of Wildhorse Pass, must be the result of repetition by imbricate faults. These faults, however, cannot be observed in the field. What can be observed is a wide area with scattered, very poor outcrops of quartzite, sandy dolomite, and cherty dolomite appearing beneath extensive cover of float from the same rocks. Poor outcrop also required that the Oxyoke Canyon-Beacon Peak be mapped at times with the Nevada Formation, the Pilot Shale mapped with the Joana Limestone, and the quartzite of the Devil's Gate Limestone not be mapped separately. Tectonic attenuation as well as the poor outcrop is responsible for the

mapping procedures.

Within the Hoodoo Hills Havoc, both high and low-angle faults are present. For most faults the dip cannot be measured directly, but outcrop patterns reveal the attitude of the fault surfaces. The low-angle faults dip uniformly toward the east. Two attitudes on the Rye Patch fault south of Cow Camp Spring dip 46° and 50° toward the east. Grooves along the fault plane trend S80E and plunge 25° to the east. This lower angle of plunge more closely resembles my impression of the dip of the fault surface in the vicinity of Picture Canyon. In contrast the high-angle faults dip toward the west; a measured dip on the fault surface in Picture Canyon dips 78° toward the west.

Rye Patch Fault. The longest and best exposed of the low-angle faults, the Rye Patch fault, can be traced from just south of Wagon Canyon to the southern end of the Havoc, although the relations at its southern termination remain unclear as several faults merge (Figures 15, 16). The fault extends for 7.5 km, and has a sinuous outcrop trace caused by its low dip. The fault cannot be strictly planar, because exposures 500 m apart have different attitudes. Through most of its exposed length, the Joana Limestone forms the footwall of the fault. Except for minor brecciation directly beneath the fault, limestone of the Joana

Figure 15. Rye Patch Fault.

This fault places the brecciated Nevada Formation over the well bedded Devil's Gate Limestone. The picture was taken near the southern end of the Rye Patch fault.

Figure 16. Vertical Beds in Havoc.

These vertical beds occur on the southwestern end of the Hoodoo Hills Havoc, on the southwest side of hill 5450. The beds belong to the Devil's Gate Limestone, and in this area a complex pattern of faults marks the end of the Rye Patch fault.

Figure 15.

Figure 16.

shows no greater deformation than that of the Devil's Gate which underlies it. Both the Devil's Gate and the Joana show disruption of bedding below the Rye Patch fault, which is best developed in the quartzite beds of the Devil's Gate or the shaly limestone of the Pilot. These rocks pinch out along strike and show small offsets (up to several meters) along high-angle faults. This disruption of bedding, however, extends from the west side of the range to the Rye Patch fault, and does not increase toward the low-angle fault. This suggests that the footwall of the Rye Patch fault may belong to another low-angle fault block bounded by a fault concealed at depth rather than the continuous section suggested in section D-D'.

The Nevada Formation forms the hanging wall of the Rye Patch fault for most of its exposed length. In contrast to the footwall, the hanging wall shows extreme brecciation along the trace of the fault (Figure 15). The amount of deformation decreases upward, so that limestone above the Nevada of the hanging wall resembles that in the footwall. Formations in the hanging wall appear to have been thinned during faulting.

The Rye Patch fault truncates structures in the footwall. These include several high-angle, east-west trending faults. Tertiary sedimentary rocks are not cut by the Rye Patch fault, and Horse Spring rocks unconformably overlie

brecciated rocks in the hanging wall north of Picture Canyon. These Tertiary sedimentary rocks occur on the west side of a high-angle fault that elevates lower Paleozoic rocks on its eastern side to form the eastern part of the Hoodoo Hills Havoc. These Tertiary rocks dip steeply toward the east, 26° and 45° at two places south of Wagon Canyon.

Joe May Guzzler Block. West of the Joe May Guzzler, a block of Devil's Gate Limestone rests in fault contact on the Nevada Formation. The contact is a low-angle fault, and the Devil's Gate forms prominent ledgy exposures. This block has been folded into a very tight syncline which can be traced southward into a fault that terminates the block.

Valley Blocks. The valley between the Sheep Range and the Black Hills contains at least two fault blocks. North of the Cow Camp road, the higher hills to the east consist largely of Nevada Formation. These rocks form the hanging wall of a low-angle fault, along whose trace the dolomite is characteristically and thoroughly brecciated. The footwall of the fault contains an anticline with the Devil's Gate in the core and Pilot Shale on both limbs. The eastern limb of the fold is overlain by the Nevada in the hanging

wall of the low-angle fault. On the west limb of the footwall anticline, the Joana appears with vertical bedding. Exposures farther west have been too badly brecciated to retain bedding, but the Indian Springs Formation appears in two small fossiliferous patches of float.

South of the Cow Camp Road, the Devil's Gate contains another anticline. While the east limb has steeply dipping beds, once again the west limb has vertical beds just before they disappear under the alluvium. To the east another low-angle east-dipping fault carries the Nevada Formation over the Devil's Gate anticline. The Nevada in this fault block forms another anticline. Beds higher in the hanging wall have characteristic eastward regional dips, whereas just above the fault the beds become horizontal and then dip shallowly toward the west.

These folds are shown on cross sections C-C' and D-D'. The sense of overturning on the anticlines supports westward motion on the low-angle faults. The sections also show that low-angle faults concealed in the alluvium would project just above the Black Hills.

Blocks in the Black Hills. A number of thoroughly brecciated blocks of limestone are present on the east side of the Black Hills (Figure 18). The occurance of stromatoporoids and quartzite within the brecciated limestone indicates that

Figure 17. Black on White Fault.

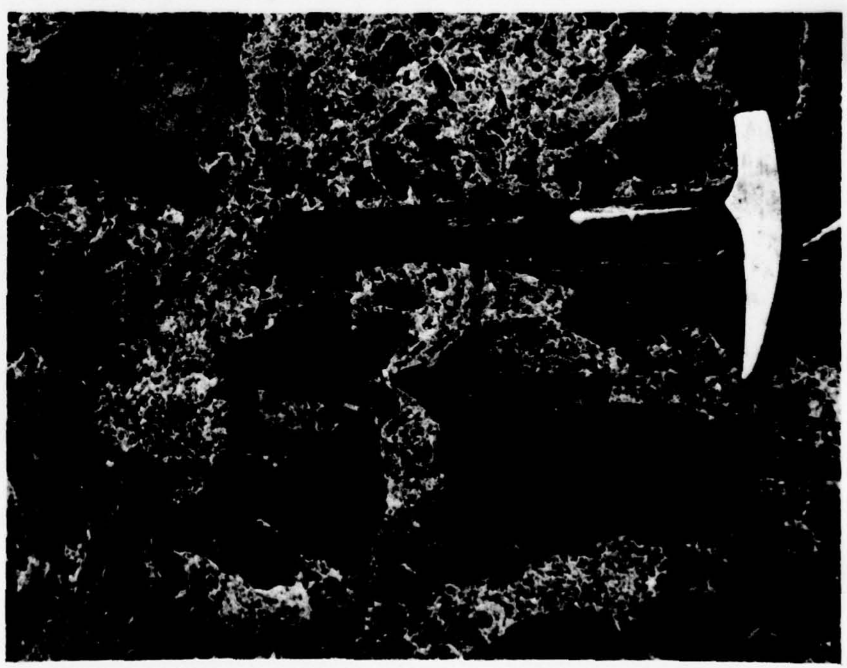
This fault surface crops out north of Rye Patch spring, and was seen from a distance in Figure 14. Both the hanging wall and footwall consist of thoroughly brecciated dolomite, which probably delongs to the Nevada Formation.

Figure 18. Limestone Breccia in the Black Hills.

Closeup of southernmost exposure of breccia in the Black Hills. This outcrop consists of limestone and minor quartzite (the black clasts above and to the left of the hammer are actually rusty quartzite). The quartzite and stromatoporoids indicate the presence of the Devil's Gate Limestone in this block, and fossil horn corals and crinoids indicate that the Joana Limestone is also present. This type of brecciation characterized the blocks in the Black Hills.

Figure 17.

Figure 18.



all the blocks contain at least some Devil's Gate Limestone. Crinoidal limestone fragments in the two southernmost blocks, along with distinctive Devil's Gate lithologies, indicate that at least those two blocks contain rocks of both the Joana and the Devil's Gate.

Blocks in the Black Hills are not continuous with the nearest outcrops isolated by alluvium only 100 m to the east. The nearest of the isolated outcrops consist of very thoroughly brecciated limestone, probably belonging to the Joana, and red shale chips of the Indian Spring containing characteristic plant fossils and goniatites. The nearest blocks in the Black Hills contain only Devil's Gate as recognizable fragments in the breccia.

Three blocks of breccia in the Black Hills are either offset or terminated by high-angle, east-west faults that also cut the unbrecciated underlying rocks of the Black Hills. One of the blocks north of Black Hills Gap rests in fault contact above the Horse Spring Formation. The fault dips 26° toward the south, about parallel to the dip of the Horse Spring rocks of the footwall. Pebble imbrications in the conglomerate consistently yield a southerly direction of sedimentary transport. The position of the southernmost block in the Black Hills suggests that both the block and the underlying rocks have been rotated clockwise, a relation important in establishing the structural

sequence of events in the area (see below).

To summarize the age relationships observed above, the blocks of brecciated rocks in the Black Hills are:

1) Emplaced after deposition of the Horse Spring Formation;
2) Emplaced before development of east-west trending high-angle faults which cut the Black Hills;
3) Older than clockwise rotation related to movement on the Las Vegas Valley shear zone.

The internal structure of the blocks in the Black Hills is different from that of the limestones in most of the Hoodoo Hills Havoc or the Long Valley block. No traces of sedimentary bedding remain and the blocks consist of a chaotic arrangement of various lithologies from the Devonian and Mississippian formations. Quartzite and stromatoporoid bearing limestone occur together, whereas in the normal stratigraphic section they occur at widely separated stratigraphic levels within the Devil's Gate. Similar chaotic mixtures do occur in the Hoodoo Hills Havoc, but most of the limestone units retain some coherence so that bedding is recognizable. These blocks in the Black Hills may have been formed by movement of Paleozoic rocks along a low-angle fault surface under conditions different from those of the Havoc.

<u>Blocks in the Desert Range</u>. Two blocks bounded at the base by low-angle faults are present on ridge crests in the mapped part of the Desert Range, and a third is present just north of the map area. Both of the mapped blocks consist exclusively of the Laketown Dolomite, although the block just north of the map area also includes distinctive upper Ordovician formations in the block.

The fault beneath the southern block dips about 13° toward the west. Rocks within the block have a strike and dip virtually identical with footwall rocks. Rocks in both the hanging and footwall consist of the Laketown Dolomite and show only minor brecciation along the low-angle fault.

The Laketown Dolomite in the hanging wall of the northern block rests on rocks of both the Laketown and Ely Springs Dolomites. This block also moved toward the west.

High-Angle Faults

Generally the high-angle faults in the Sheep Range are not well exposed because of vegetation and talus cover, so attitudes and details of the faults are indeterminate. High-angle faults in the Black Hills are well exposed and could be measured.

Major faults in the Sheep Range dip steeply to the west

and the hanging wall has moved relatively down. Topographic expression and traces of the faults are straight regardless of topography, indicating the faults have a steep dip. The 60° dip shown on the cross sections, however, represents only a best guess of the actual dip. On no fault could the direction of net slip be determined, so that the relative motion is unconstrained. Dominately dip-slip motion is consistent with the mapped relations, and these faults are interpreted as normal-slip faults.

The mapped portion of the LasVegas Range contains no significant or mappable high-angle faults. The Mormon Pass fault, which separates the Las Vegas Range from the Sheep Range, is largely concealed by alluvium, but evidence for the fault is the juxtaposition of the basal Banded Mountain Member east of the fault against the top of the Antelope Valley Limestone west of the fault. Stratigraphic omission along the fault is 1600 m. Beds east of the fault dip 10-20° to the west, whereas west of the fault beds dip 20°-30° toward the east. Thus, while this geometry has some features of a syncline, the difference in stratigraphic level and abrupt change in dip requires a fault of large displacement. Eastward rotation of the downdropped block probably accounts for the difference in bedding attitudes. The fault crosses the ridge connecting the Las Vegas and Sheep Ranges north of Twin Buttes. Its trace

can be followed, but poor outcrop does not permit accurate assessment of attitudes of the fault. To the west of Twin Buttes, the fault returns to a north-south trace and in occasional outcrops the Nevada Formation is exposed faulted against units of the upper Banded Mountain Member.

Section B-B' most clearly reveals the geometry of the high-angle faults across the Sheep Range. From the Mormon Pass fault to the Wildhorse Pass fault at the eastern edge of the Hoodoo Hills Havoc, eight high-angle normal slip faults are present. Six of these faults can be traced in outcrop. One must be inferred to account for the abnormal thickness of the Antelope Valley Limestone in the low hills on the east side of the Sheep Range, a region with many fault-isolated outcrops of the Eureka that cannot be easily connected. An east-dipping fault on the west side of the range is inferred to explain the thin outcrop of the lower Pogonip Undifferentiated.

Assuming that all the faults dip 60° and using the known stratigraphic displacement, horizontal extension of about 15% across the line of this section is calculated from the crest of the Las Vegas Range to the east side of the Hoodoo Hills Havoc. This does not include an unknown amount of extension on the Wildhorse Pass fault.

<u>High-Angle Faults in the Black Hills</u>. The Black Hills have been cut by numerous high-angle faults. One major fault trends north and repeats Cambrian rocks. Many minor faults have small displacements, and often these faults are well exposed and the fault attitudes can be determined either on the fault surface or on planar fault surfaces within the breccia zone along the fault.

The attitudes of 12 faults were measured in the Black Hills. These attitudes were not shown on the geologic map because of space restriction. The attitudes of these faults were plotted on a steronet (Figure 19). The fault pattern does not clearly represent a single stress field or the presence of obvious conjugate sets. Most of the faults trend east, dip steeply to the north, and clearly offset units in the Black Hills (plate I). Some of the scatter in this data could be due to rotation of some faults by the Las Vegas shear zone.

CHAPTER IV. INTERPRETIVE STRUCTURAL GEOLOGY AND REGIONAL TECTONICS

Data from the Sheep Range add important contraints to existing models and lead to the development of several new hypotheses about the geologic evolution of the southern

Figure 19. Poles to Fault Planes, Black Hills.

Poles to 12 high-angle faults in the Black Hills are plotted on a lower hemisphere projection. The faults are plotted on the geologic map, but the attitudes could not be shown due to space restrictions. Minor rotation by the Las Vegas Valley shear zone could influence the results, but almost all of these faults occur in the northern part of the Black Hills away from significant shear zone rotations.

Great Basin. Areas to the south of the Sheep Range have been well mapped. Adjacent areas to the west, north, and east have not been mapped in detail, and work in those areas ranges from reconnaissance mapping to detailed stratigraphic studies. Some interpretations from existing regional data can be made, but detailed mapping is required to establish the complex regional history.

Gass Peak Thrust

Five features of the Gass Peak thrust will be discussed: 1) its regional correlation, 2) its time of emplacement, 3) its behavior at depth, 4) it magnitude of displacement, and 5) its post-thrusting relations in the region. For many of these features, definitive answers elude us because the critical relations are not exposed, have not been studied, or do not exist.

Regional Correlation. (Figure 20). The Gass Peak thrust can be correlated confidently with the Wheeler Pass thrust of the northwest Spring Mountains. Both thrusts juxtapose the Stirling Quartzite over the Bird Spring Formation, and share similar Paleozoic facies that differ significantly from other thrust plates in the region. Burchfiel (1965) suggested this correlation of the two thrusts which have

Figure 19.

Poles to fault planes, Black Hills

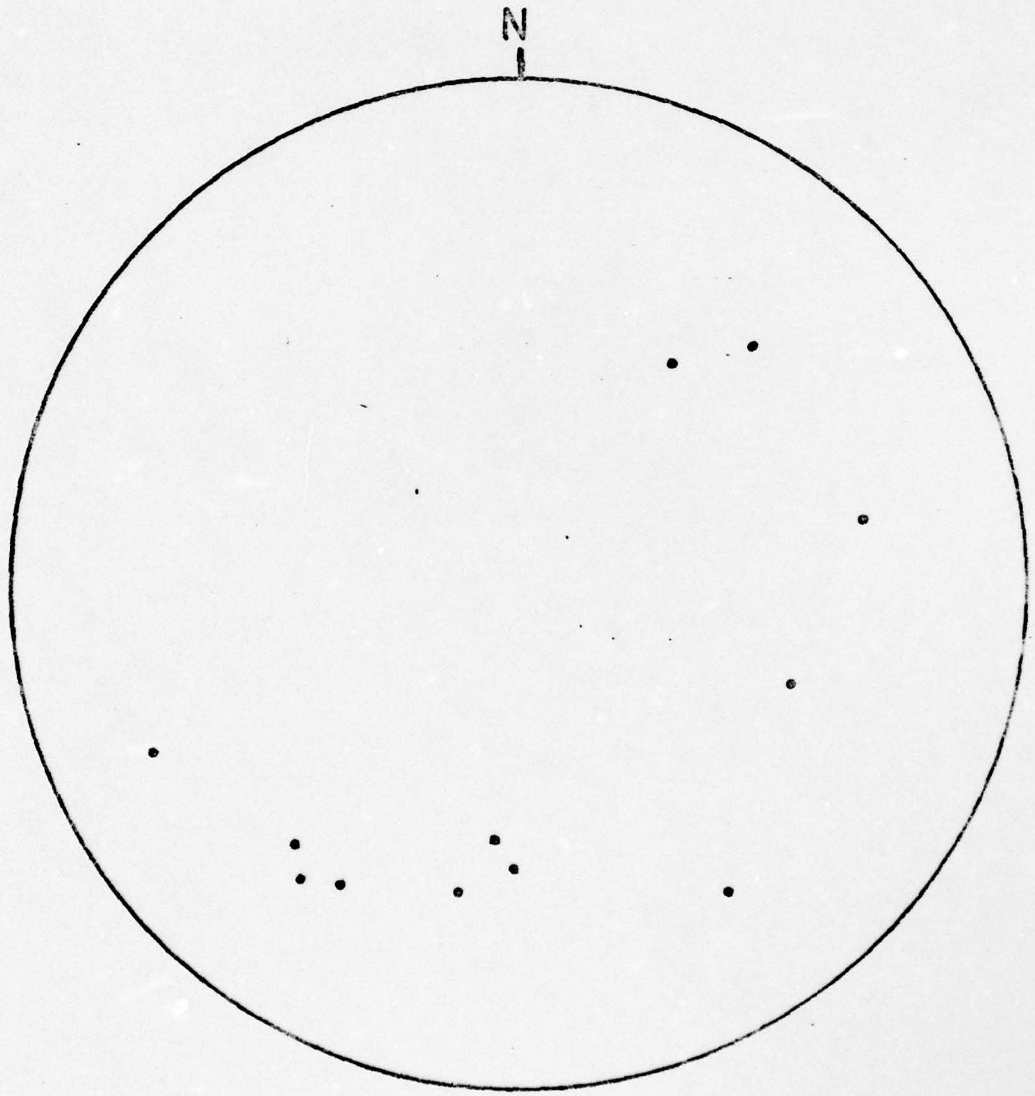


Figure 20. Location of Regional Thrust Faults.

Thrust faults and other faults referred to in the text are indicated on this map. Outlines of the mountain ranges are very generalized, with much of the Tertiary and Cenozoic rocks omitted.

Abbreviations used: CT, Contact thrust; MPT, Mesquite Pass thrust; MT, Montgomery thrust; PF, Prospector fault; and WPT, Winters Pass thrust.

been offset over 43 km by the Las Vegas Valley shear zone, and the correlation has been accepted by all subsequent workers in the region.

Burchfiel and others (in prep.) suggest the correlation of the Shaw thrust with the Wheeler Pass thrust. The Shaw thrust crops out only in the northwestern corner of the Nopah Range. No further southward continuation of this thrust has been recognized.

Northward, Armstrong (1968) suggested upper plate continuity from Gass Peak to the Canyon Range of Utah. But from just north of Wamp Spring in the Las Vegas Range to the Wah Wah Range some 150 km to the northeast, the trace of the fault does not crop out. Extensive Tertiary volcanic rocks cover Paleozoic rocks and the thrust in this region. In the Wah Wah Range of southern Utah, the thrust belt reappears, and two thrust faults are present (Miller, 1966). The structurally higher Wah Wah thrust juxtaposes Eocambrian clastic rocks over Pennsylvanian limestone. The structurally lower Blue Mountain thrust places Cambrian carbonates over Jurassic sandstone. In general these relationships suggest correlation with the Gass Peak and the Muddy Mountain thrusts respectively. The overturned fold and thrust belt in the Bird Spring Formation of the foot wall continues northward from Wamp Spring and the upper plate Cambrian and Ordovician carbonate rocks in the hanging wall in the

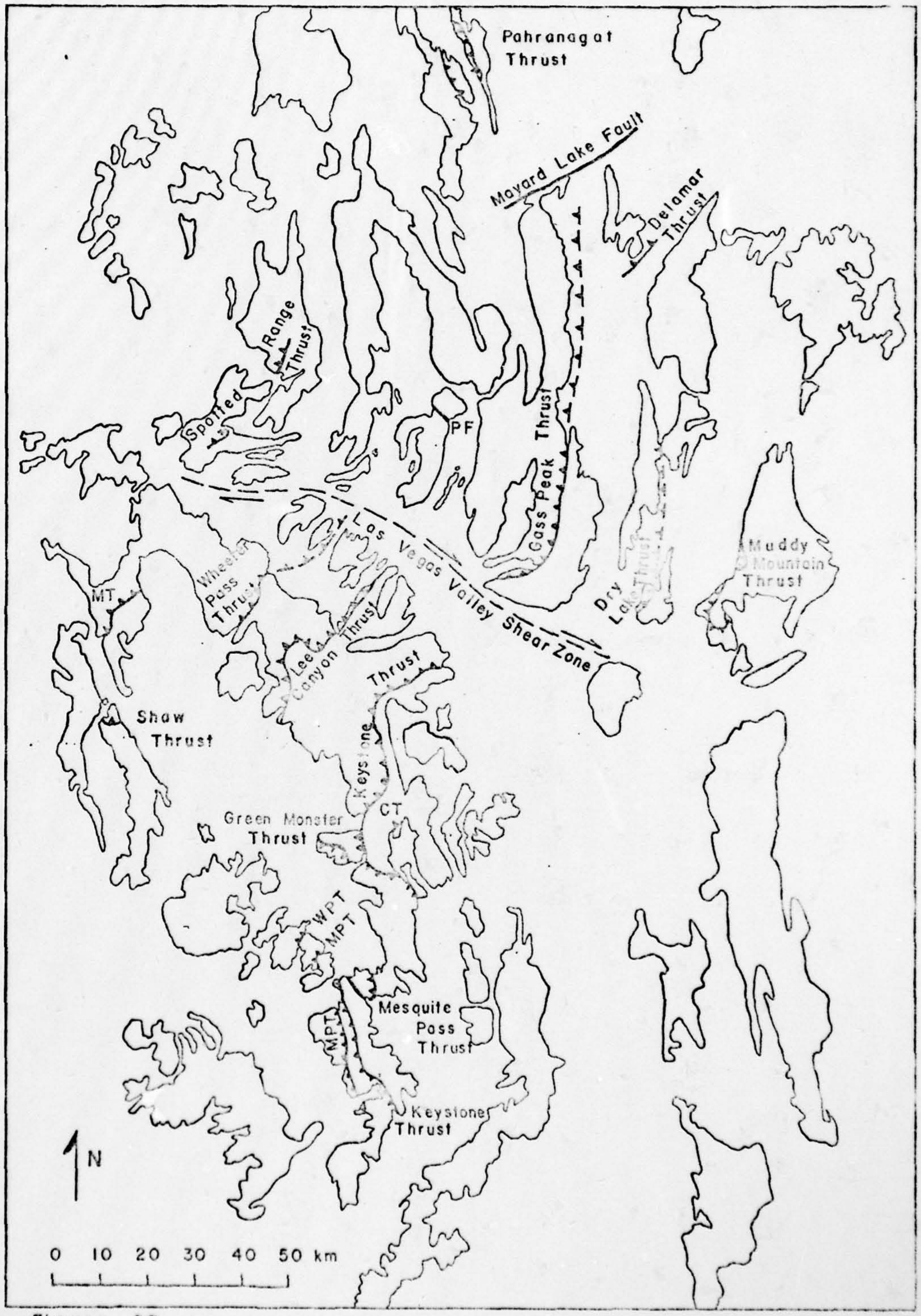

Pahranagat Thrust
Mayard Lake Fault
Delamar Thrust
Range Thrust
Spotted
PF
Gass Peak Thrust
Las Vegas Valley Shear Zone
Muddy Mountain Thrust
Dry Lake Thrust
Wheeler Pass Thrust
MT
Lee Canyon Thrust
Thrust
Shaw Thrust
Keystone
CT
Green Monster Thrust
WPT
MPT
Mesquite Pass Thrust
MPT
Keystone Thrust
N
0 10 20 30 40 50 km

Figure 20.

Sheep Range continue along strike. The actual trace of the thrust does not crop out but can be inferred from the fold belt and juxtaposition of rocks (Longwell and others, 1965; Tschanz and Pampeyan, 1970). The Maynard Lake fault truncates the inferred trace of the Gass Peak thrust, which is then lost until it reappears in Utah.

The Gass Peak thrust does not correspond to the thrust plates in the Pahranagat Range which appear to the north of the Maynard Lake fault. The difference in Paleozoic stratigraphy between the two areas has already been discussed (Figure 4). The thrust in the Pahranagat Range may instead correlate with the Spotted Range thrust, displaced 48 km along a right-lateral Maynard Lake fault (Tschanz and Pampeyan, 1970). If this is the case the continuation of the Gass Peak thrust must be offset toward the east by the Maynard Lake fault, which is the general trend the thrust would have to reappear in the Wah Wah Range.

The Delamar thrust occurs south of the Maynard Lake fault and east of the Gass Peak fold and thrust belt. The actual thrust does not crop out, but has been inferred from an overturned syncline in Carboniferous rocks and the presence of Cambrian rocks in a structurally higher position in the Delamar Range (Tschanz and Pampeyan, 1970). Tschanz and Pampeyan (1970, pp. 102, 107) correlated the Delamar

thrust with the Gass Peak thrust and located the Gass Peak thrust on the east side of the Sheep Range. Their correlation suggests the Delamar thrust would be a klippe of the Gass Peak thrust, which if true would require a minimum southeast thransport of 15 km.

Detailed study of the stratigraphy in the Delamar Mountains would help to better constrain the correlation of thrust plates in the region. Stewart (1974) described sections of the Eocambrian rocks at Delamar and Caliente. Because easternmost exposures of these units characteristically first appear in the Wheeler Pass-Gass Peak thrust plate, they suggest correlation with the Gass Peak plate. But Stewart's Eocambrian sections occur north of the Maynard Lake fault, and the thrust plate to which they belong is uncertain. The measured section of the Laketown and Sevy Dolomites south of the Maynard Lake fault in the Delamar Mountains (Heckel and Reso, 1962), where the two formations have a combined thickness of 570 m, suggests that the Delamar section belongs to a Paleozoic facies belt originally located farther west than rocks of the Arrow Canyon Range which are part of the lower plate of the Gass Peak thrust. *Rocks in the Delamar Range are* presently on structural strike with those in the Arrow Canyon Range, which suggests the Delamar rocks are displaced eastward.

Webster and Langenheim (1979) suggest that the Delamar thrust might correlate with the Dry Lake Thrust. The Dry Lake thrust occurs on the east side of the Arrow Canyon Range and is exposed at two places. At Apex Summit the thrust places rocks of the Pogonip Group above the Bird Spring Formation. In the Arrow Canyon Range, the Nopah Formation rests on overturned Pogonip, and the fault dips 60° northwest (Langenheim and Mahlburg, 1973). If the Delamar and Dry Lake thrusts are correlative, the thrust must cut down section northward and across depositional strike.

As a third possibility, the Delamar thrust may represent an entirely different thrust plate, an echelon to the Gass Peak thrust. It could have increased displacement northward as displacement is transferred from the Gass Peak thrust to the Delamar thrust.

The Dry Lake thrust forms the next major thrust to the east of the Gass Peak thrust. Fleck (1970a) correlated this fault with the Deer Creek thrust of the Spring Mountains. The next major thrust to the east, the Muddy Mountain thrust, correlates with the Keystone thrust of the Spring Mountains, a correlation that led to Longwell's (1960) recognition of the Las Vegas Valley shear zone.

West of the Sheep Range, the probable correlation of the Pahranagat and Spotted Range thrust has already been

mentioned. In the Nevada Test Site, Barnes and Poole (1968) suggested that both the Spotted Range and Pahranagat thrusts represented erosional klippe from the CP thrust, which would then have at least 40-55 km displacement. These thrusts have been correlated with the Last Chance thrust west of the Death Valley area (Burchfiel and others, 1970).

The nature of the Prospector fault in the Desert Range led me to consider the possibility that it is the Gass Peak thrust emerging at the surface. Longwell (1945) gave the dip of the Prospector fault as 17° to the southwest. The fault cuts downsection in the Eocambrian clastic sequence, but what rocks form the footwall remains unclear. In his original map Longwell (1945) showed the Eocambrian rocks in contact with those of the Ordovician. In a later version of the map at essentially the same scale (Longwell and others, 1965), a sliver of Cambrian Bonanza King and Nopah Formations was shown between the Prospector fault and Ordovician rocks in the hanging wall. Clearly the Desert Range, and especially this fault which brings up the Eocambrian section, must be mapped in detail before the fault can be accurately interpreted. Reconnaissance mapping suggests that this fault cannot be the Gass Peak thrust. If the Prospector fault were the Gass Peak thrust, rocks in the southern part of the Desert Range would be in its lower plate. Before thrusting these rocks

would have occupied a position between the Sheep Range and the Arrow Canyon Range. Formations in the Desert Range are thicker and their facies are consistent with having been deposited originally west of the Sheep Range during the Silurian and lower Devonian. Thicknesses of the Laketown Dolomite and the Nevada Formation were estimated using the map outcrop pattern. A thickness of 230 and 257 m was estimated at two places for the Nevada Formation, which is essentially the same as the 245 m estimated in the Sheep Range. Three incomplete sections of the Laketown Dolomite were estimated as 366, 413, and 460 m thick in the Desert Range-- all significantly thicker than the 300 m for the same rocks in the Sheep Range. Thus, rocks in the Desert Range are best assigned to the upper plate of the Gass Peak thrust.

Time of Deformation. For most of the thrust faults in southern Nevada the age of deformation is poorly constrained. This proves also to be the case for the Gass Peak thrust. The thrust must be younger than the youngest unit involved in the thrusting, and older than the oldest beds overlying the thrust. This limits formation of the Gass PEak thrust to the interval between middle Permian and Miocene. This represents a long interval of geologic time, particularly when models of the regional history (e.g. Burchfiel and

Davis, 1972, 1975) suggest that the thrusting is Mesozoic.

The best dated portion of the thrust belt occurs in the Clark Mountains over 100 km to the south of Sheep Range. Dated plutons bracket thrusting and document two stages of deformation. The earliest folding and thrusting events occurred before 200 m.y.B.P., and a later episode of thrusting occurred between 135 and 95 m.y.B.P. Several events fall in the interval between these episodes (Burchfiel and Davis, 1971, 1977). Unfortunately the Gass Peak thrust cannot be correlated with any of the thrusts in the Clark Mountains.

In the Spring Mountains to the south of the Sheep Range, only the two easternmost thrusts can be dated. Carr (1977) found conglomerates below the Contact thrust plate near Goodsprings. The conglomerates contain clasts of Triassic and Jurassic units, clasts of Paleozoic rocks believed eroded from the Contact plate, and an interlayered tuff with a K/Ar age of 150±10 m.y.B.P. (Carr, 1977). These data suggest the Contact thrust developed about 150 m.y.B.P. The Keystone plate overrides the Contact plate, and can be tightly constrained by two dates. In the Clark Mountains the Keystone is cut by a 95±5 m.y.B.P. pluton (K/Ar, Burchfiel and Davis, 1971), whereas in the Muddy Mountains the Muddy Mountain thrust postdates tuffs dated at 98.4 and 96.4 m.y.B.P. (K/Ar, Fleck, 1970). These

ages tightly constrain the emplacment of the Keystone thrust system at about 95 m.y.B.P.

This evidence indicates that thrusting in southern Nevada took place during the Mesozoic. Secor (1962) found cobbles of the Wood Canyon Formation in channels cut into the Aztec Sandstone that are overridden by the Keystone thrust. Since only the Gass Peak-Wheeler Pass thrust exposes the Eocambrian rocks, this suggests that the Gass Peak-Wheeler Pass thrust was emplaced and eroded before about 95 m.y.B.P. when the Keystone developed. Narrower age control, especially a lower bound, is not currently possible.

Décollement Behaviour of the Gass Peak Thrust. The behaviour at depth of the Gass Peak thrust remains open to interpretation. Vincelette (1965) tentatively concluded that the Wheeler Pass thrust probably did not flatten at depth into a basal décollement, although he was unable to suggest what did occur at depth. Ebanks (1965) interpreted his mapping in the Gass Peak quadrangle to suggest that the Gass Peak thrust flattened at depth, inferring that the thrust detached along a massive conglomerate near the base of the Stirling.

My mapping shows extensive tectonic slicing in the lower part of the Gass Peak plate, which Ebanks also noted,

and that the Stirling is not everywhere along the thrust contact. If a décollement horizon does exist, it has been extensively modified in the schuppen zone at the base of the thrust plate. The Wheeler Pass thrust also exposes various units along its sole, from the Stirling Quartzite to the Carrara Formation.

Rocks above the Gass Peak thrust dip steeply toward the west, in the same direction as the thrust. The complexity of the schuppen does not permit determination of whether the thrust or bedding dips more steeply. Westward within a few kilometers of the thrust trace, bedding in the upper plate becomes more gently dipping which would require that the thrust plane also flatten if it has a décollement geometry or that it continues downward to involve crystalline basement if it does not have décollement geometry. If the thrust does flatten, it must still cut downward into older Eocambrian rocks in order to expose rocks as old as the Johnnie Formation in the Desert Range.

No décollement horizon can be determined anywhere to the west of the Gass Peak thrust, because lower plate rocks are not exposed, but if a décollement horizon does exist, it must be below the Johnnie Formation. Stewart (1970) measured 1590 m of Johnnie Formation from an incomplete section in the Desert Range. The underlying Noonday Dolomite may be present in the Desert Range, as Longwell and

others (1965) reported 1280 m of Johnnie in the Desert Range and suggested that dolomite at its base could represent the Noonday.

Burchfiel (1964) and Vincelette (1964) determined that the contact between the Johnnie and Stirling formations in the northwestern Spring Mountains was not marked by the Johnnie thrust, a thrust regarded as the décollement for the Wheeler Pass thrust by Nolan (1929). The Wheeler Pass thrust thus cannot be directly related to a décollement horizon.

Burchfiel and others (1974) discussed the deeper geometry of the thrust faults in the Spring Mountains. They suggested three possibilities for the thrusts at depth: 1) the thrusts override deeper, unseen thrust plates; 2) the thrusts cut downsection and include additional strata not seen at the surface; or 3) the thrusts cut downsection and include Precambrian crystalline basement. They also encountered a space problem if the thrust faults were assumed to have a décollement geometry, a problem especially severe for the Wheeler Pass thrust.

The Gass Peak (Figure 21) thrust must cut downsection from the stratigraphic levels exposed in the Las Vegas Range. However, this alone cannot explain a geometric problem at depth; there is not enough thickness of Eocambrian rocks to explain the different levels of the same

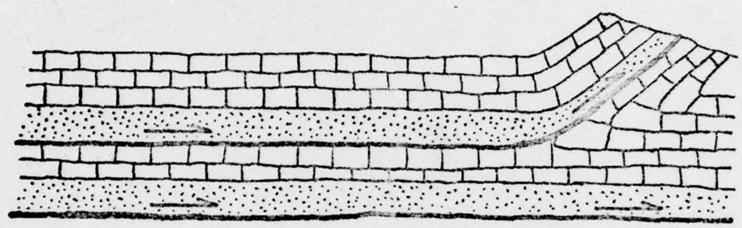
Figure 21. Interpretive Cross Sections of Gass Peak Thrust.

Three interpretive cross sections for the deeper behaviour for the Gass Peak thrust are indicated. Rocks on the right side of the diagram belong to the upper plate of the Dry Lake thrust, and those on the left side belong to the Gass Peak allochthon. East is to the right, and the effects of Tertiary low-angle and high-angle faults have been removed. Topography is hypothetical, but may represent conditions at the end of Sevier thrusting.

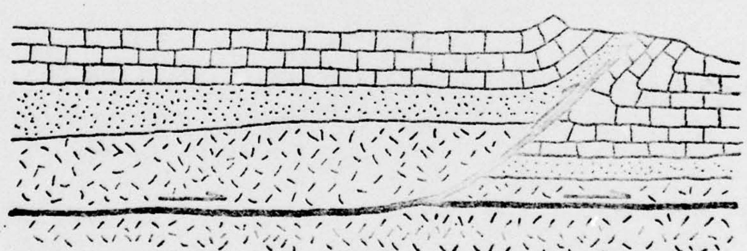
Case 1 assumes décollement within the Eocambrian clastic wedge; case 2 assumes décollement within the Precambrian crystalline basement; and case 3 assumes no décollement. Not shown is a fourth case, in which the Gass Peak thrust overrides an unseen thrust slice present only in the subsurface. For discussion of these geometries in terms of the Spring Mountain thrusts, see figure 6 of Burchfiel and others (1974).

Block pattern, Paleozoic carbonate sequence; dot pattern, Eocambrian clastic wedge; and dash pattern, Precambrian crystalline basement.

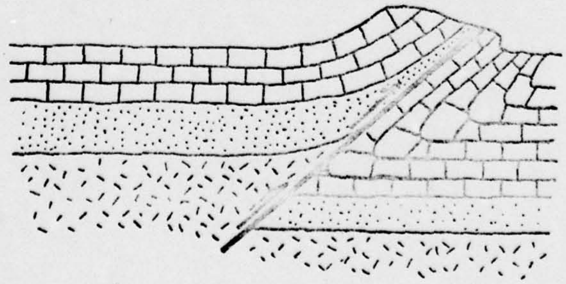
Figure 21. Interpretive cross sections of Gass Peak thrust



Case 1: Décollement within Eocambrian clastic wedge



Case 2: Décollement in crystalline basement



Case 3: No décollement

stratigraphic horizon in the upper and lower plates of the Gass Peak thrust. On section A-A', more than 4000 m separates the base of the Pogonip Group in the subhorizontal rocks of the lower plate from where the same rocks would project in the subhorizontal rocks of the upper plate. This suggests that if the thrust detached along a décollement horizon, a 4 km thick part of the lower plate extends an unkown distance to the west beneath the upper plate or that Precambrian basement has been involved in the upper plate.

The thrust faults in the Clark Mountains exhibit décollement geometry even when they flatten into the Precambrian crystalline basement. Anisotropy in the stratified rocks played no role in controlling the flattening of the thrusts at depth (Burchfiel and Davis, 1971). Even though these thrusts do not correlate with the Gass Peak thrust, the data suggest that the behavior of the Clark Mountain thrusts might serve as a model for the Gass Peak thrust. The Clark Mountain thrusts that involve the basement occur west of the frontal thrust of the Sevier belt in that area, a position analogous to that of the Gass Peak thrust. The Winters Pass thrust brings up rocks of the Eocambrian clastic wedge but cuts down section to finally flatten within Precambrian gneisses (Burchfiel and Davis, 1971). Erosion has revealed significant cross strike exposures to establish the relations in the Clark Mountains,

whereas in the Sheep Range only the trace of the ramp of the Gass Peak thrust is exposed and the deeper geometry of the thrust plate remains concealed at depth.

Displacement on the Gass Peak Thrust. Burchfiel and others (1974) noted the difficulty in constraining the displacement on the Wheeler Pass thrust in the Spring Mountains. Assuming that the thrust involved the Precambrian basement, they estimated displacements in the range 11-33 km. Décollement geometry would require at least 33 km displacement.

Décollement within the Eocambrian clastic wedge in the Sheep Range would require that a substantial thickness of the lower plate rocks extends beneath the upper plate within the map area. To the west of the Sheep Range, all rocks seen at the surface appear to belong to the upper plate of the Gass Peak thrust as far west as the outcrop of the Spotted Range thrust some 60 km to the west. The rocks all belong to the lower Paleozoic and upper Precambrian, which would suggest that younger rocks in part of the lower plate underlie this area. This further suggests a minimum of 60 km of shortening for the Gass Peak thrust. Extreme Cenozoic extension north of the Las Vegas Valley shear zone to be discussed later could reduce this figure by half.

If the Delamar thrust discussed earlier does represent a klippe of the Gass Peak thrust, minimum displacement on

the thrust must be at least 15 km.

If the Gass Peak thrust continues downward into the basement with dip of 30° and has a stratigraphic displacement of 5900 m, its horizontal displacement would be 10.2 km.

Post-Thrusting Relations. It can be inferred that at the end of Sevier thrusting the upper plate of the Gass Peak thrust consisted of sub-horizontal rock units with few significant structures. Only along the eastern part of the plate where the thrust ramps did rock units have significant west dips. These relations can be inferred by reversing post-thrusting faults and rotations on cross sections D-D' and E-E'. This interpretation agrees with the observation of Armstrong (1968), noted that the Paleozoic strata in the Sevier orogenic belt, except where ramps or large folds were present, generally had shallow dips when the initial Tertiary sedimentary rocks were deposited.

Low-Angle Faulting

Widespread low-angle denudational faults have been mapped in the Cordillera, but very few have been accurately dated(Crittenden and others, 1978). Some faults can be

dated as Tertiary, and rarely a Mesozoic age can be proven. This leaves many of the faults poorly constrained in time, and the orogenic models of particular geologists play a role in assigning an age to the faults. The low-angle faults that have received intensive study occur in two areas. To the northeast of the Sheep Range, the hinterland of the Sevier orogenic belt in east-central Nevada and western Utah contains extensive denudation faults (Armstrong, 1972). Southeast of the Sheep Range a chain of metamorphic core complexes extends across the eastern margin of the thrust belt and contains numerous low-angle faults (Davis and Coney, 1974).

Armstrong (1972) reviewed the evidence for the denudation faulting in the hinterland of the Sevier belt, and concluded that the bulk of the low-angle faults were not related to Mesozoic thrusting. In part his conclusion followed from his belief that the thrusts formed in a Mesozoic compressional regime, and the low-angle faults formed in a Cenozoic extensional regime. Other workers have not been convinced by Armstrong's arguments. For example, both Hose and Danes (1973)and Hintze (1978) regarded the denudation faults as forming contemporaneously with the thrusting and intimately involved with Sevier age deformation. With the lack of evidence to date the faults--Hose (1977) could only constrain the age of the denudation

faults to between late Jurassic and Oligocene, and Hintze (1978) could only constrain the age of the faults between Triassic and Oligocene-- mechanical models for deformation play an important role in assigning a date to the denudation faults. A Mesozoic age for the denudation faults would favor gravity gliding for emplacement of the thrusts, whereas a Teriary age would favor a post-thrusting age for the denudation faults. Many areas of denudation faulting in the Sevier hinterland are also related to metamorphic rocks, and some workers have suggested a relationship between the two (Davis and Coney, 1979).

Recent work southeast of the Sheep Range has focused on the chain of metamorphic core complexes in California and Arizona. Workers there agree on a Tertiary age for the denudation low-angle faulting, but do not agree on the mechanism or relations of faults to metamorphism. According to the some workers (Davis and Coney, 1979), metamorphism, mylonitazation, doming, and denudation faulting are all related and result in the creation of a metamorphic core complex. Other work in the Whipple Mountains (Davis and others, 1979) suggests that metamorphism and mylonitization preceded the detachment faulting and that the processes were not directly related. Whether these differences represent variations on a single theme or reflect profound differences in the geologic histories of the

individual mountain ranges, only additional work will tell.

In many areas the low-angle faults in the Great Basin involve Tertiary volcanic and sedimentary units. Examples of this type of thin-skinned extension include Anderson's (1971) work in the Lake Mead area and Profett's (1977) work in the Yerrington District.

Closer to the Sheep Range, Paleozoic units have been involved in low-angle faulting in the Desert Range (Longwell, 1945), and in the Virgin Mountains (Seager, 1970).

Low-angle faults in the Sheep Range are important because they clearly document the occurrence of denudational faults in areas removed from any Mesozoic or Tertiary igneous or metamorphic activity. This type of fault is here present in sedimentary rocks, without any evidence for an associated thermal event.

In the Sheep Range the low-angle faults occur placing older-on-younger rocks as well as younger-on-older rocks. The Long Valley and Hidden Forest blocks place younger-on-older rocks with consequent absence of section. The Rye Patch fault and most of the low-angle faults in the Hoodoo Hills Havoc repeat section, and place older-on-younger rocks.

Long Valley Block. I interpret the Long Valley block as originating to the east of its present position. The presence of Devi's Gate and Joana formations of similar

stratigraphy on the east side of the Sheep Range suggests that the Long Valley block came from a nearby position, such as the ridge underlain by the Nevada Formation about 1 km east of the block. The geometry of the basal fault and attitudes in the block suggest that the block slid to the west and rotated on listric faults. This explains the doubling of section and the repetition of units. Beds in the block dip more steeply than rocks in the footwall because of rotation on listric faults. The Gass Peak allochthon formed a terrane of subhorizontal dips at the time of low-angle faulting. The low-angle faults would have originally dipped to the west, but have been rotated by the younger high-angle faults to now dip shallowly to the east. A similar mechanism probably explains the poorly exposed Hidden Forest block and the ious fragments of blocks near the top of the Sheep Range.

Hoodoo Hills Havoc. The Hoodoo Hills Havoc represents a more complicated situation. Folds which appear overturned toward the west (see section C-C' and D-D') support the interpretation that here also the fault blocks moved toward the west. But the older-on-younger faults, such as the Rye Patch fault or the faults in the low hills east of the Black Hills, require at least two phases of displacement. In a first phase, the Devil's Gate and the Joana were

downdropped between the Sheep Range and the Black Hills. This could have occurred by either high-angle or low-angle extensional faulting. The fact that the Devil's Gate and the Pilot have been folded (section D-D') suggests that they were emplaced along a basal low-angle fault and that the rocks in its hanging wall were folded. The structurally lowest and most western block includes the youngest rock, and successively higher and more eastward blocks contain older rocks at the base.

Section D-D' illustrates this geometry. East of the Black Hills is a fault bounded slice of Devil's Gate and Joana limestones which could either be resting on Ordovician rocks continuous with the Black Hills or on structurally lower low-angle fault slices. Above this there is another slice containing Nevada and Devil's Gate formation rocks. The relation of the Devil's Gate and Joana formations that form the cliff at the west edge of the Hoodoo Hills cannot be determined. Bedding in the cliffs has been disrupted, so that these rocks could represent another low-angle fault slice and not be continuous downward as shown on the cross section. This slice is overlain by two slices containing Nevada and Devil's Gate formations whose units have been tectonically thinned. Some

Joana is present in the second slice. Structurally higher is a slice consisting of Laketown Dolomite and Oxyoke Canyon-Beacon Peak Members that are tectonically thickened and cut on the east by the Wildhorse Pass fault which brings the Havoc into contact with the Bonanza King Formation of the Sheep Range.

Despite present dips toward the east, I infer that the low-angle faults initially dipped and moved toward the west. As discussed above, at the end of Sevier age deformation the strata in the Sheep Range appear to have been broadly sub-horizontal west of the trace of the Gass Peak thrust. They now dip an average of about 30° to the east, suggesting rotation along the Tertiary normal faults of about 30°. Tertiary sedimentary rocks in the Hoodoo Hills Havoc also generally dip toward the e with average dips of about 25-30° but with dips locally as much as 45°. These rocks abut the high angle faults and occur consistently on their downthrown side. The rotation of the Tertiary sedimentary rocks means that the younger high-angle faults caused the rotation. The Tertiary rocks could have had initial dips of up to 10-15°, and pebble imbrications in the coarse conglomerates near Rye Patch Spring suggest that the sediments were derived from the east. An eastward source area and initial westward dip could thus increase the rotation of the Tertiary sediments by the high-angle

normal faults. If the grooves along the Rye Patch fault record a 25° dip for the fault, then the Rye Patch fault would have dipped shallowly to the west before rotation on the high-angle faults. The faults in the hills east of the Black Hills currently dip very shallowly to the east, so that even moderate rotation would reverse their dips back to the west.

Along the east side of the Black Hills, the brecciated blocks are different from the other blocks involved in the low-angle faulting. These blocks have been extensively brecciated, even though the blocks contain limestones from the upper Devonian and Mississippian part of the section which usually retain their bedded character. The outcrop pattern of rounded ridges and complete internal mixing more closely resembles landslide deposits such as those described by Krieger (1977) in southeastern Arizona. They could represent either a variation in a spectrum of structural deformation, or a discrete episode of younger landsliding. As one block overlies Tertiary sedimentary rocks, they probably formed after most of the low-angle faults.

<u>Desert Range and Points West</u>. The region to the west of the Sheep Range has been mapped only in reconnaissance, so that only the general features of its geologic history are

known. Longwell (1945) first described the low-angle faults of the Desert Range. Brief mapping reveals that those faults do exist, and dip to the west. They rest on very steeply dipping Paleozoic units, so that if the low-angle faults preceded rotation of the range the faults must initially have dipped steeply over 70°. Alternatively these faults could postdate rotation of the range, an interpretation I prefer. All the faults can be traced back upslope to a logical source terrain, a feature not present for the low-angle fault blocks in the Sheep Range.

Descriptions of the ranges west of the Sheep Range (Longwell and others, 1965; Tschanz and Pampeyan, 1970) reveal tantalizing indications that much of the area has suffered extensive low-angle faulting. Longwell believed that the Desert and Pintwater Ranges formed a large anticline, but the reconnaissance work of Tschanz and Pampeyan showed that the junction of the two ranges was so complexly faulted that an anticline existed only in the broadest sense. Both county reports mention a large fault block on the east side of the Pintwater Range, 1 x 5 km in size. This block consists of thoroughly brecciated Bonanza King Formation resting with fault contact on Tertiary conglomerates. The Tertiary rocks dip 25° to the east, whereas the fault dips 30° to the east. The source for the block appears to be in the Desert Range, 13 km to the east. I

interpret this block as a block emplaced by low-angle faulting which has been rotated to reverse its dip.

In the Pintwater Range, Tschanz and Pampeyan (1970) describe abundant fault blocks and slivers of the Devonian rocks. They infer that Devonian rocks were thrust over Ordovician rocks. The younger-on-older relation suggests that the rocks were juxtaposed by low-angle extensional faults similar to those in the Hoodoo Hills Havoc and the Long Valley block.

Only detailed mapping can reveal the extent of the low-angle extensional faulting in the Desert and Pintwater Ranges. They have been mapped only in reconnaissance, and similar early reconnaissance mapping in the Sheep Range failed to discover the extensive low-angle fault block terraines there. But on the basis of the limited information available and on regional considerations to be developed later, I suggest that the area west of the Sheep Range has been an area of significant extension by denudational faults.

Relation to Chaos. Wright and Troxel (1973) have interpreted the chaos structure of the Death Valley region as forming near the base of tilted fault blocks. The faults have a listric form, and near the base of the tilted blocks several faults merge causing attenuation of the stratigraphic

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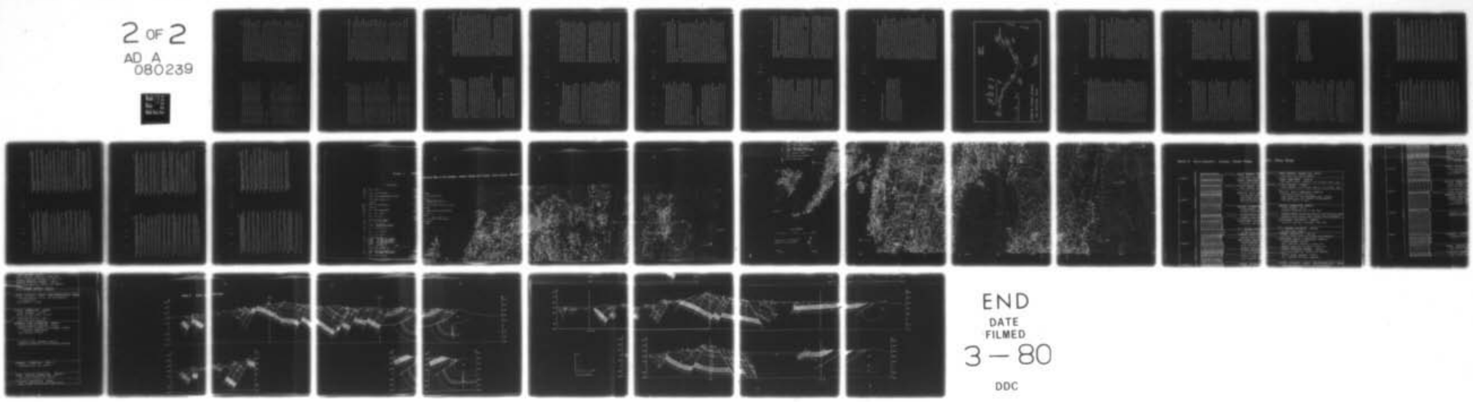

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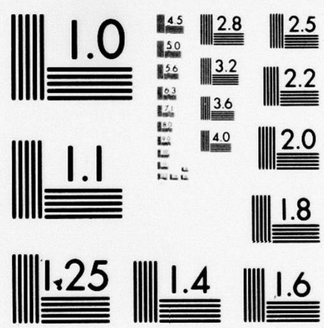

MICROCOPY RESOLUTION TEST CHART

section. The anastamosing faults bound relatively unfractured rocks which are separated by zones of gouge to form chaos. The blocks in my area are not separated by gouge, are more thoroughly brecciated, and do not correspond with the chaos structure of the Death Valley area. Thus I do not use the term chaos, although the structural style in the Death Valley chaos and in the Sheep Range must represent variations in a general extensional regime characterized by listric normal faults.

High-Angle Faults

The major high-angle faults in the Sheep Range trend north-south, and post-date the major episode of low-angle faulting discussed above. These hig[illegible]gle faults are responsible for the eastward rotation of all the rocks in the Sheep Range, because both Paleozoic and Tertiary strata dip consistently east. This rotation must be accomplished by the unseen Mormon Pass fault, as major change in attitude occurs across this fault (section B-B'). Beyond this fault to the west, the other faults consistently downdrop the blocks on their western side, but there is no change in overall rotation of the range as dips remain relatively constant across the Sheep Range.

The cross sections (Plate II) do not show any flattening

of the high-angle faults in the Sheep Range, because there is no direct evidence for the listric nature of the faults. However, the general listric nature of faults in the southern Great Basin has been established (e.g. Wright and Troxel, 1973). The Sheep Range normal faults probably flatten at depth, but I cannot determine at what depth this would occur. Consequently the faults have been drawn as continuing downward at a dip of 60°.

Developing a series of tilted fault blocks from a horizontal slab must require adjustment with the blocks. I suggest that this adjustment has taken place by distributed bedding place slip, a feature noted above in the disucssion of the stratigraphy. Two formations, the Eureka Quartzite and the Ely Springs Dolomite, appear to have especially localized this readjustment. Contacts of both formations are frequently faulted, and in one place along the crest of the Sheep Range the Ely Springs has been faulted out. The same area also shows a repetition of the Eureka (section D-D'). Bedding plane faults are probably also prominent in the Pogonip Group, and the variations in member thicknesses along strike on the west side of the Sheep Range suggest faulting along bedding surfaces.

The high-angle faults exposed in the Sheep Range cannot be directly related to the low-angle faults exposed in the Hoodoo Hills Havoc. Clearly the Sheep Range faults

do not flatten at stratigraphic levels that could explain the Havoc. But the two sets of faults could represent sections through different structural levels of listric normal faults. The high-angle faults are exposed near their steep upper portion, while the low-angle faults represent a deeper erosional level of older listric faults.

The age of the high-angle faults in the Sheep Range cannot be well constrained, although most are younger than the Horse Spring Formation. Ekren and others (1968) dated two sets of high-angle faults in the Nevada Test Site. Older northeast and northwest-trending faults were active about 26.5 - 17 m.y.B.P. The north trending faults, responsible for the present topographic grain of the area, began to form between 17 and 14 m.y.B.P. At least some of the ranges did not achieve significant relief until after 11 m.y.B.P., but by 7 m.y.B.P. the region had essentially reached its present topographic outline.

Las Vegas Valley Shear Zone

Longwell (1960) first proposed the Las Vegas Valley shear zone as a major zone of right-lateral shear between the Spring Mountains and the numerous ranges to the north. He initially postulated that motion on the shear zone developed synchronously with thrusting and continued into

the Tertiary, but later work has established an exclusively Tertiary age for the shear zone.

Longwell initially proposed about 40 km of offset across the shear zone, based on a correlation of the Keystone and Muddy Mountain thrusts (Longwell, 1960). Burchfiel (1965) correlated the Gass Peak and Wheeler Pass thrusts to estimate more than 43 km of motion. He also established that surface rupture along the shear zone terminated at the Specter Range. Stewart and others (1968) suggested 40-64 km of displacement based on offsets of isopachs and facies lines in rocks of all Paleozoic systems. Longwell (1974) revised his estimate to 64 km of displacement based on offset of the source terrain for distinctive granite clasts in the Thumb Formation, and corrected the estimated displacement of the Gass Peak-Wheeler Pass thrust to 67 km, with the justification that drag near Wheeler Pass had not been considered.

The age of movement along the shear zone is well constrained. Ekren and others (1968) suggested that deformation did not begin until after 17 m.y.B.P. Fleck (1970b) constrained the motion to the period 15-10.7 m.y. B.P., which yields a rate of motion of 1.0 -1.5 cm/yr. Longwell (1974) limited motion to 17-11 m.y.B.P. Thus the motion along the shear zone appears to be synchronous with the initiation of the north-trending high-angle faults

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The age of movement along the shear zone is well constrained. Ekren and others (1968) suggested that deformation did not begin until after 17 m.y.B.P. Fleck (1970b) constrained the motion to the period 15-10.7 m.y. B.P., which yields a rate of motion of 1.0 -1.5 cm/yr. Longwell (1974) limited motion to 17-11 m.y.B.P. Thus the motion along the shear zone appears to be synchronous with the initiation of the north-trending high-angle faults

in the Nevada Test Site.

The mapped area shows only slight clockwise rotation by the Las Vegas Valley Shear Zone. In the Gass Peak quadrangle Ebanks (1965) mapped extensive deformation, including the rotation of the Gass Peak thrust. The effect of this rotation decreased toward the north in Ebank's area, and no structures in the Hayford Peak quadrangle could be attributed to displacement on the shear zone.

Two areas on the west side of the map area contain changes in attitudes that can be interpreted as rotations by the Las Vegas Valley shear zone: 1) the change in bedding attitudes at the southern end of the Black Hills, and 2) the change in trend at the southern end of the high-angle Wildhorse Pass fault. Both trend changes occur only at the southern end of the mapped area, where the trend changes rapidly. Bedding attitudes in the southernmost Black Hills suggest rotation of over 90° in a clockwise sense about a near-vertical axis. Almost all the rotation appears within the southernmost 2 km of the range. Similarly, the Wildhorse Pass fault must also have a sharp clockwise rotation of about 90° in order to exit Joe May Canyon without appearing on the south side of the canyon's mouth. Deformation along the shear zone must account for the appearance on Fossil Ridge of the only outcrops of the Nopah Formation

on the east side of the Sheep Range. Ebank's (1965) section C-C' clearly shows that the presence of Fossil Ridge demands faulting which he relates to the Las Vegas Valley shear zone. Longwell (1974) also must have been aware of the anamalous position of Fossil Ridge, as his location map shows a thrust fault underlying the ridge. Since he did not discuss the evidence for this thrust fault, it is difficult to evaluate its presence. Perhaps detailed mapping in the Corn Creek Springs quadrangle will document clearly the deformation along the shear zone and reveal the reason for the appearance of the Nopah Formation.

Rotation of the Desert Range. Gillette and Van Alstine (1979) presented evidence for a 36° clockwise rotation of the Desert Range. They compared the paleomagnetic pole for early Cambrian to middle Middle Cambrian rocks in the Desert Range to that for similar age rocks in the cratonal section of the Grand Canyon. The difference in the pole positions for the two areas required rotation about a vertical axis. They suggest that the rotation could be due to oroflexural bending or rotation during thrust emplacement.

Their Desert Range data is 15 km north of the edge of my map area. Since the deformation along the Las Vegas Valley shear zone appears to be restricted to the extreme

southern ends of the ranges, I do not believe that their 36° rotation could be due to rotation along the shear zone. The rotation could be due to a larger scale oroflexural rotation of the entire range, as envisioned by Albers (1967), and to strike-slip faults farther north in Lincoln County. As a further possibility, rotation could be related to motion on low-angle Tertiary faults. I have already commented on the Prospector fault which involves the Eocambrian section in the Desert Range where Gillett and Van Alstine measured their section; this fault may have caused significant rotating but its geometry and movement history are poorly known.

Regional Extension Model

Burchfiel's (1964) mapping in the Specter Range established that the Las Vegas Valley shear zone did not extend as a surface fracture through the Specter Range. Large scale oroflexural bending (60 km) is present, but there is no surface fault. Motion increases eastward along the shear zone by a combination of bending and actual faulting. Crustal extension must compensate for this displacement. The Wheeler Pass thrust is about 47 km east south east from the Specter Range. On the north side of the shear zone, the distance from the Specter Range to the

Gass Peak thrust is about 90 km along an east south east line. If the two thrusts once formed a continuous plate now displaced by 43 km, extension of almost 100% in a region north of the shear zone could account for the observed geologic relations.

South of Las Vegas Valley, the Spring Mountains have been thoroughly mapped. The area consists of a single mountain range without major Tertiary extension faults. North of the shear zone, the topography is dramatically different. Alluvium-filled valleys separate a series of mountain ranges. Extensive extensional fault terrains exist west of the Sheep Range, and may occur elsewhere farther west. In a very crude approximation, simply closing the valleys north of the shear zone would restore the region to about half its present width. This represents a great over-simplification because not all of the valleys can represent extended terrain. Extension can also occur in the ranges, for instance in the Desert Range where steep dips and repeated section suggest significant extension. Given our knowledge of the gelogy north of the shear zone, I consider 100% extension possible. Other regions in the Great Basin have experienced 100% extension, such as the Yerrington District (Profett, 1977), the Eldorado Mountains (Armstrong, 1971), and the Death Valley area (Davis and Burchfiel, 1973).

Anderson (1973) and Bohannon (1979a, b) have described the left-lateral Lake Mead fault system, which may have up to 65 km displacements during the period 13-10 m.y.B.P. This system has displacement and movement history similar to the Las Vegas Valley shear zone. The low-angle extensional terrain in the Eldorado Mountains occurs on the south side of the Lake Mead fault system, and Anderson (1973) proposed that the strike-slip faulting could take up motion between an extending terrain south of the fault and a non-extending region to the north.

Also in 1973, Davis and Burchfiel suggested that the Garlock fault represented an intracontinental transform fault between regions of differential extension. Both Anderson (1973) and Davis and Burchfiel (1973) suggested that the Las Vegas Valley shear zone could also mark the boundary between two zones undergoing different amounts of extension.

Although the general features of the Las Vegas Valley shear zone and the Lake Mead fault system are understood, detailed relations remain uncertain.

The eastern termination of the Lake Mead system may be related to the boundary between Basin Ranges and the Colorado Plateau (Bohannon, 1979a), but the details remain obscure. Of greater fundamental importance for this discussion the Las Vegas Valley shear zone and the Lake Mead

fault system must intersect and interact-- under the alluvium of Las Vegas Valley where their geometry is unconstrained.

Ignoring the complications of the interaction between the faults, I see the Las Vegas Valley shear zone and the Lake Mead fault system acting together to control Tertiary extension between the Specter Range and the Colorado Plateau (Figure 22). Extension occurred to the north of the right-lateral northwest-trending Las Vegas Shear Zone, and to the south of the left-lateral northeast-trending Lake Mead system. Extension might total 40 km on each of the systems, and spread across an area of 200 km from the Colorado Plateau to the Specter Range this figure correponds to overall extension of about 20%. The extension appears to be zonal and not uniformly distributed throughout the area.

East of the Hoodoo Hills Havoc, the bulk of the Sheep Range and the Las Vegas Range do not appear to have greatly extended. The Arrow Canyon Range has not yet been entirely mapped, but the detailed studies already done there should have revealed low-angle faulting if it were present. To support the interpretation of little extension east of the Hoodoo Hills Havoc, the distances between the Wheeler Pass and Keystone thrusts, and between the Gass Peak and Muddy Mountain thrusts appear both equal and about 35 km. Thus

Figure 22. Strike-Slip Faults and Extension.

Speculative interpretation of extension by low-angle faulting in the vicinity of the Sheep Range and its relation to strike-slip faults. Areas of extension are indicated by east-west arrows, and represent: the area north of Las Vegas Valley (this study), the Mormon Mountains (B. Wernicke, Pers. comm., 1979), the Virgin Mountains (Seager, 1970), and the Eldorado Mountains (Anderson, 1971). Location of the Lake Mead fault system after Bohannon (1979a).

in this region the shear zone has simply displaced two regions that have not extended differentially.

Complications to this picture arise at the eastern end of the Lake Mead fault system. In the Mormon Mountains, an extensive low-angle fault terrain had recently been identified and is being mapped (B. Wernicke, pers. comm., 1979). Southeast of the Mormon Mountains and straddling two splays of the Lake Mead fault system (Bohannon, 1979a) are the northern Virgin Mountains where Seager (1970) mapped extensive low-angle gravity glide structures. Depending on the relative displacement of various strands in the Lake Mead fault system, the Virgin Mountain extensional terrain could be north of, within, or south of the Lake Mead system. If its position is south of the Lake Mead fault system it would help to balance the extension in the Mormon Mountains. But extension need not balance of both sides of the shear zones. The system could open as a wedge with greater extension on one side. If greater extension took place north of the Lake Mead and Las Vegas Valley systems, the Basin Ranges could slide eastward past the Colorado Plataeu on a fault from the Lake Mead system bounding the Colorado Plateau and the Basin Ranges. This model views low-angle faulting and strike-slip faulting as intimately related (Anderson, 1973). Bohannon (1979a) showed Tertiary sedimentation in the Lake Mead

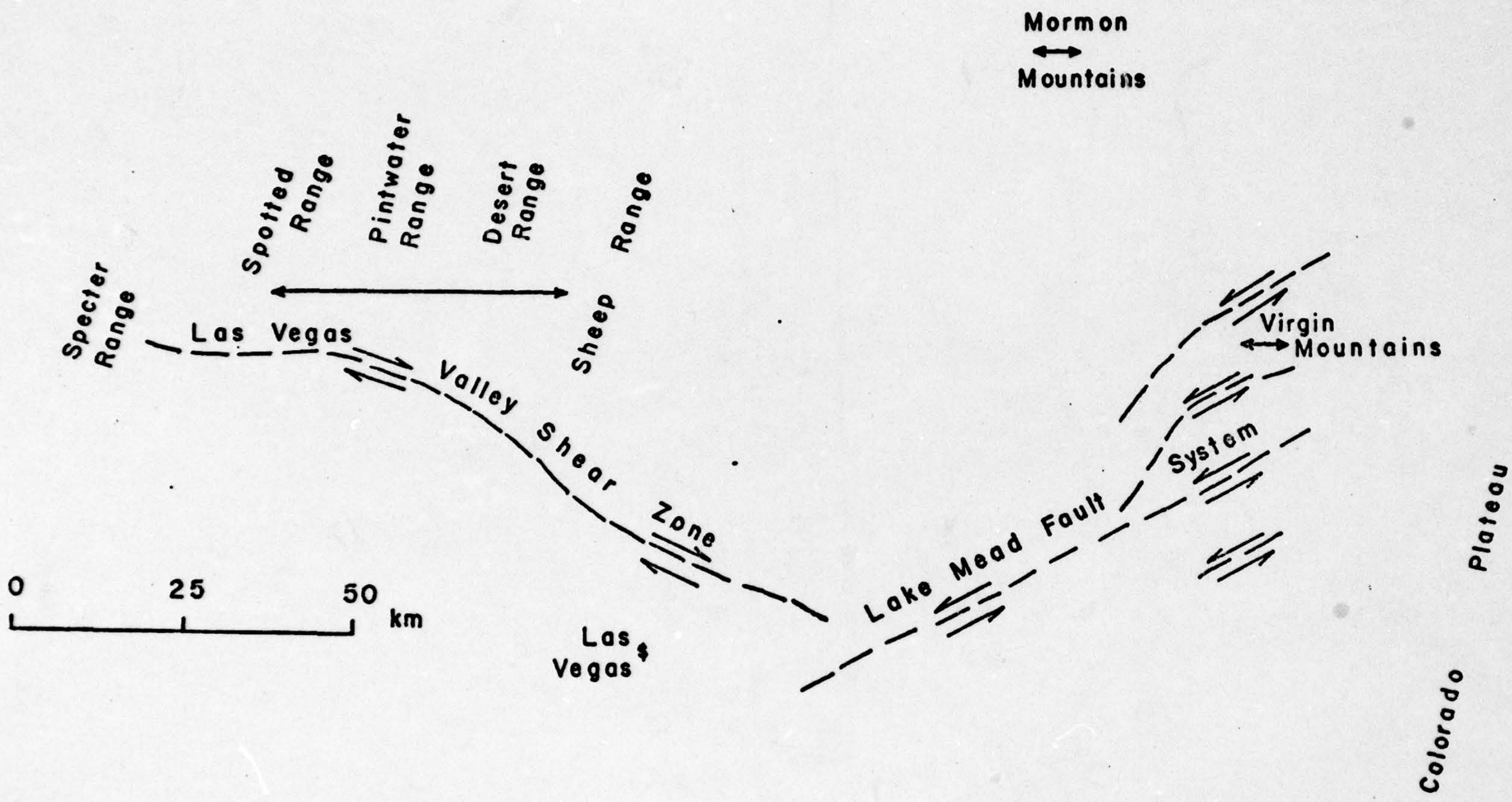

Figure 22. Tertiary Extension and Strike-Slip Faults

region occurring simultaneously with motion on the Lake Mead fault system. In the Sheep Range, I infer that motion on the low-angle faults preceeded rotation of the Black Hills by the Las Vegas Valley Shear Zone. This drag rotation could represent a late stage related to the shear zone deformation, and earlier fault displacement on the shear zone could have occurred synchronously with low-angle faulting and deposition of the Horse Spring Formation.

In this model of extension north of the Las Vegas Valley shear zone, the extended crust should be thinner than unextended crust south of the shear zone. Geophysical evidence contradicts this prediction. A seismic refraction line from Kingman, Arizona to the Nevada Test Site showed a change in crustal thickness from 28 km south of the shear zone to 32 km north of the shear zone. The change occurred in less than 25 km along the profile (Roller, 1964). A second line from Lake Mead to Mono Lake in California found a sharp change in the depth to the Moho 48 km from Lake Mead, which was correlated with the shear zone. The Moho was 2.5 km deeper to the north (Johnson, 1965). Since both these lines cross Las Vegas Valley, they could be influenced by the interaction of the Lake Mead fault system with the Las Vegas Valley shear zone. If the area underneath Las Vegas Valley underwent extreme extension, the geophysical profiles could simply be

reflecting different degrees of extension in two extending areas. Additional work will clearly be required to resolve the question of crustal extension in this part of Nevada.

CONCLUSION: GEOLOGIC HISTORY, SHEEP RANGE AND VICINITY

In summary, mapping reveals the following geologic history of the southern Sheep Range and vicinity:

1. Miogeosynclinal sedimentation, latest Precambrian to at least mid-Permian. The sequence begins with a transgressive wedge of conglomerate, quartzite, and shale of upper Precambrian to Middle Cambrian age followed by limestone and dolomite during the remainder of Cambrian and lower Ordovician time. Periodic influxes of silty material mark major cycles in the sedimentary record. Above the distinctive Euréka Quartzie, dolomite forms Upper Ordovician, Silurian, and lower Devonian formations. The remainder of the upper Paleozoic sequence is largely limestone, with minor clastic influxes which partly record the distal influences of the Antler orogeny.

2. Sevier thrusting along the Gass Peak thrust. The Gass Peak thrust fault can only be dated as forming between middle Permian and Miocene time, although a latest Jurassic age appears most likely. The thrust has a

stratigraphic eastward displacement of 5900 m, a probable minimum displacement of 10 km and displacement as great as 60 km is possible if the thrust has a décollement type geometry. The extension would be reduced to 30 km if the thrust had décollement geometry and the region north of the Las Vegas Valley shear zone had undergone 100% extension.

Evidence suggests the thrust does flatten at depth, but does not appear to be controlled in any specific way by the stratigraphic sequence. The Gass Peak thrust and all its correlative thrusts expose the thick Eocambrian clastic wedge, whose presence may influence detachment. The thrust must cut down section to the west to expose thicker sections of the Eocambrian wedge in the Desert Range. As much as 4 km of lower plate rocks may extend as far west as the Spotted Range.

3. Low-angle faulting of probable Tertiary age. Low-angle faults are present near the crest of the Sheep Range where they place younger rocks on older rocks, and in the *Hoodoo Hills Havoc* where they place older rocks on younger rocks. At least seven large blocks are present: two different blocks atop the Sheep Range, the Long Valley and Hidden Forest blocks; at least three blocks in the Hoodoo Hills Havoc; and two blocks in the low hills between Cow Camp and the Black Hills. Fault blocks moved

down gentle slopes toward the west. Hanging wall blocks show intensive brecciation, indicating shallow level deformation. This low-angle faulting may include significant areas north of Las Vegas Valley to the west of the Sheep Range, which could have experienced 100% extension over a distance of 90 km. Early movement on the Las Vegas Valley shear zone may have begun at this time.

4. Deposition of Horse Spring Formation conglomerates and interbedded tuffs, probably Miocene or 15 m.y.B.P. These may have occurred synchronously with low-angle faulting and movement the Las Vegas Valley shear zone, although no sediments can be demonstrated to be older than low-angle faulting or strike-slip motion.

5. Landsliding or additional low-angle faulting emplaced the blocks currently exposed on the east side of the Black Hills which clearly overlie Tertiary sedimentary rocks.

6. High-angle faults. High-angle faults cut the Sheep Range, the Hoodoo Hills Havoc, and the Black Hills. The faults typically trend north-south and downdrop rocks on their western side. They cause rotation of the Sheep Range, with most of the rotation caused by the easternmost fault, the Mormon Pass fault. These high-angle faults account for perhaps 15% extension within the Sheep Range. Bedding plane slip compensates for rotation on

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the faults.

7. Right-laterial drag along the Las Vegas Valley shear zone. Movement on the Las Vegas Valley shear zone rotated rocks in the Black Hills and the Wildhorse Pass fault bounding the Hoodoo Hills Havoc. Rotation due to shear zone displacement is limited to the southern end of the ranges.

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I.

Plate I. Geol

EXPLANATION

Quaternary	Qal	Alluvium
Tertiary	Ths	Horse Spring Formation
	MDc	Breccia of Mississippian-Devonian Carbonates
	Pzb	Breccia of Paleozoic Units
unconformity		
Pennsylvanian Permian	PPbs	Bird Spring Formation
nonsequence		
Mississippian	Mis	Indian Springs Formation
	Mj	Joana Limestone
	Mp	Pilot Shale
Devonian	Ddg, Dq	Devil's Gate Limestone Dq: Quartzite Bed
	Dn, Dnob	Nevada Formation Dnob: Oxyoke Canyon Sandstone & Beacon Peak Dolomite
Silurian	Sl	Laketown Dolomite
Ordovician	Oes	Ely Springs Dolomite
	Oe	Eureka Quartzite
	Opg: Oa (Oaa, Oar, Oap); Op (Opu, Opl)	Pogonip Group Oa: Antelope Valley Limestone Oaa: Aysees Peak Member Oar: Ranger Mountains Member Oap: Paiute Ridge Member Op: Lower Pogonip Undivided Opu: Upper Unit Opl: Lower Unit
Cambrian	€n	Nopah Formation
	€nd	€nd: Dunderberg Shale
	€bb, €bp	Bonanza King Formation €bb: Banded Mountain Member €bp: Papoose Lake Member
	€c	Carrara Formation
	€wc	Wood Canyon Formation

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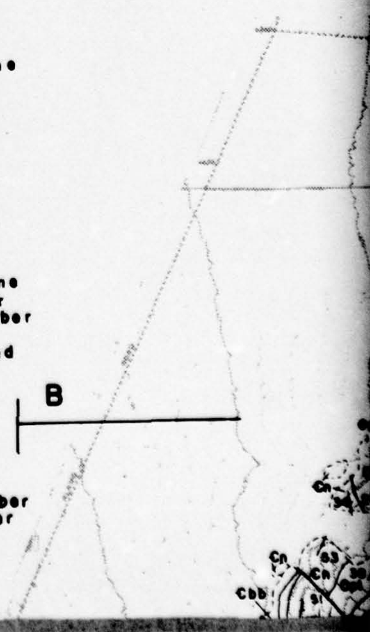
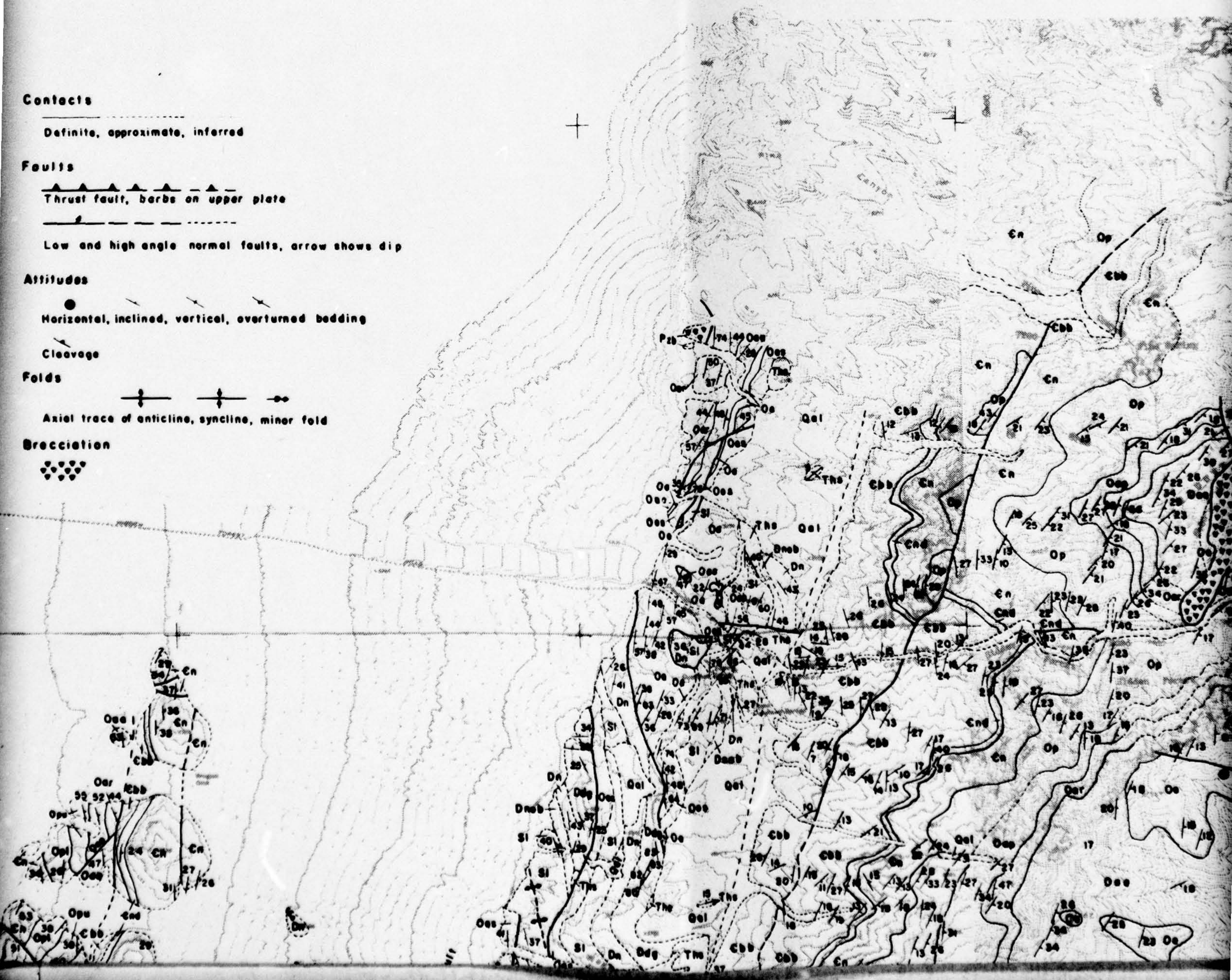


2

Geologic Map of the Southern SHEEP RANGE and Vicinity, Clark County, Nevada



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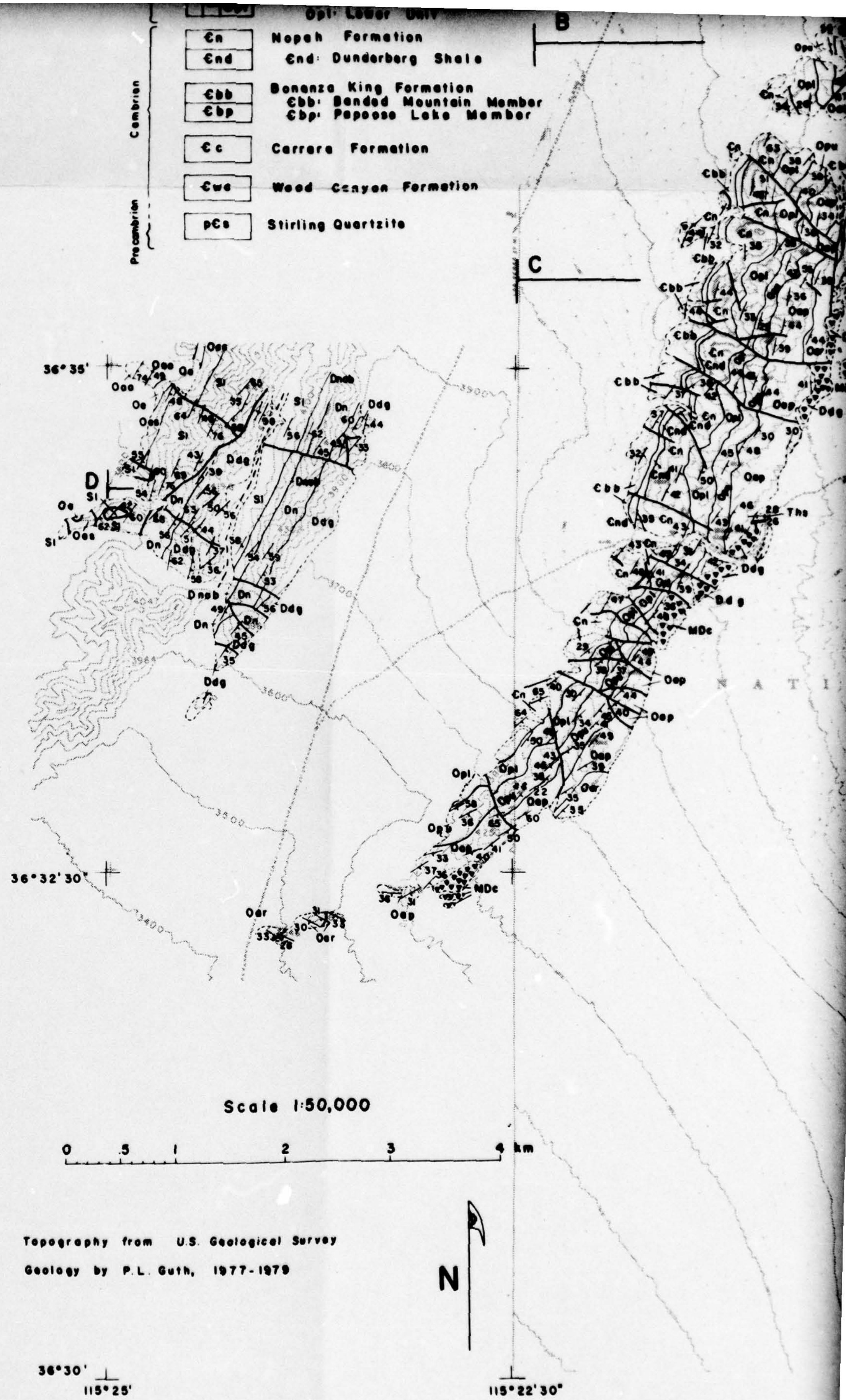


Opl: Lower Unit
Cambrian
€n Nopah Formation
€nd €nd: Dunderberg Shale
€bb €bp Bonanza King Formation
€bb: Banded Mountain Member
€bp: Papoose Lake Member
€c Carrara Formation
€wc Wood Canyon Formation
Precambrian
p€s Stirling Quartzite
B
C
D
36°35'
36°32'30"
Scale 1:50,000
0 .5 1 2 3 4 km
Topography from U.S. Geological Survey
Geology by P.L. Guth, 1977-1979
N
36°30'
115°25'
115°22'30"

5


Rib Patch Fault
Wildhorse Pass Fault
E
115°20'
115°17'30"
115°15'

7

8

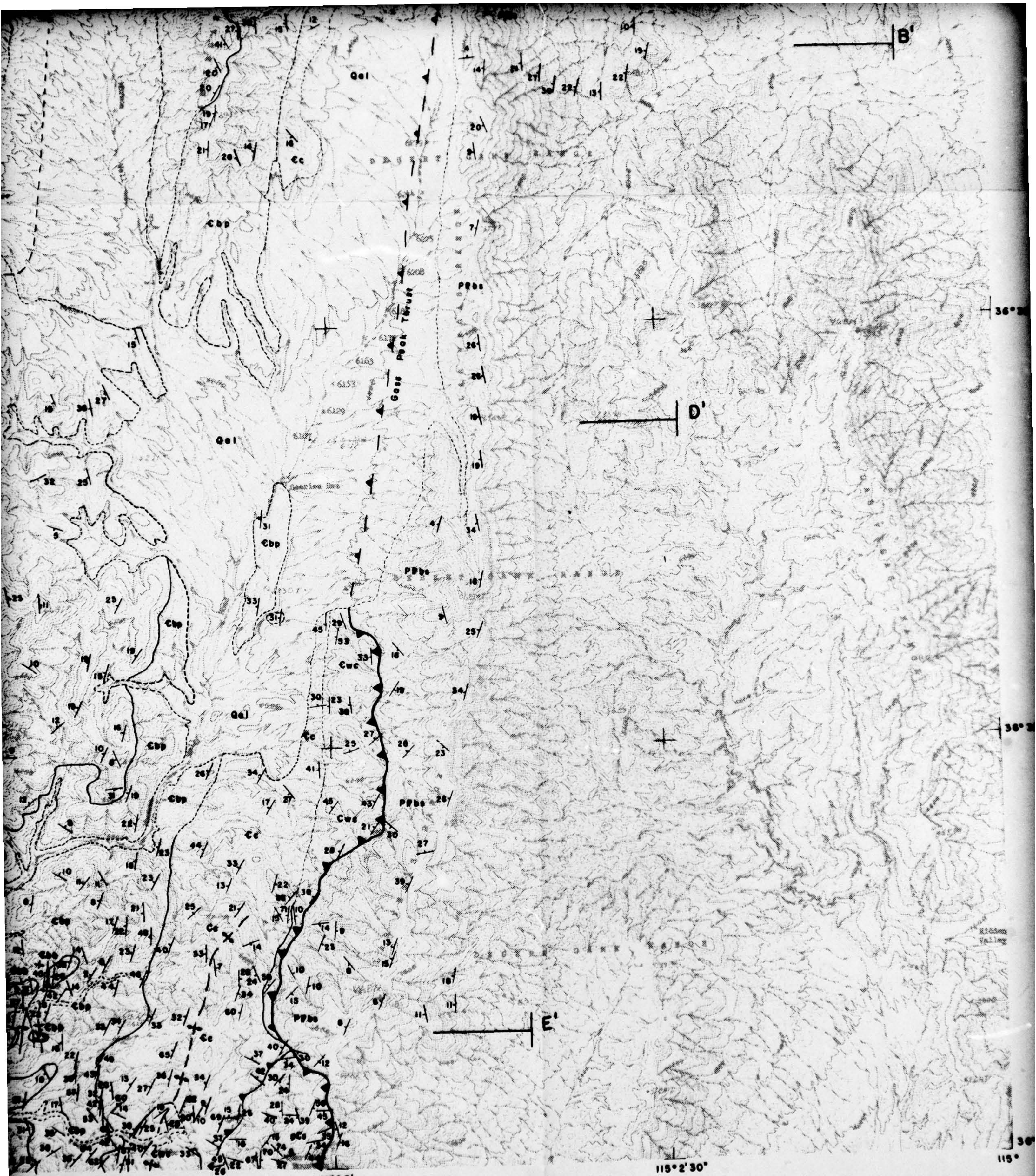
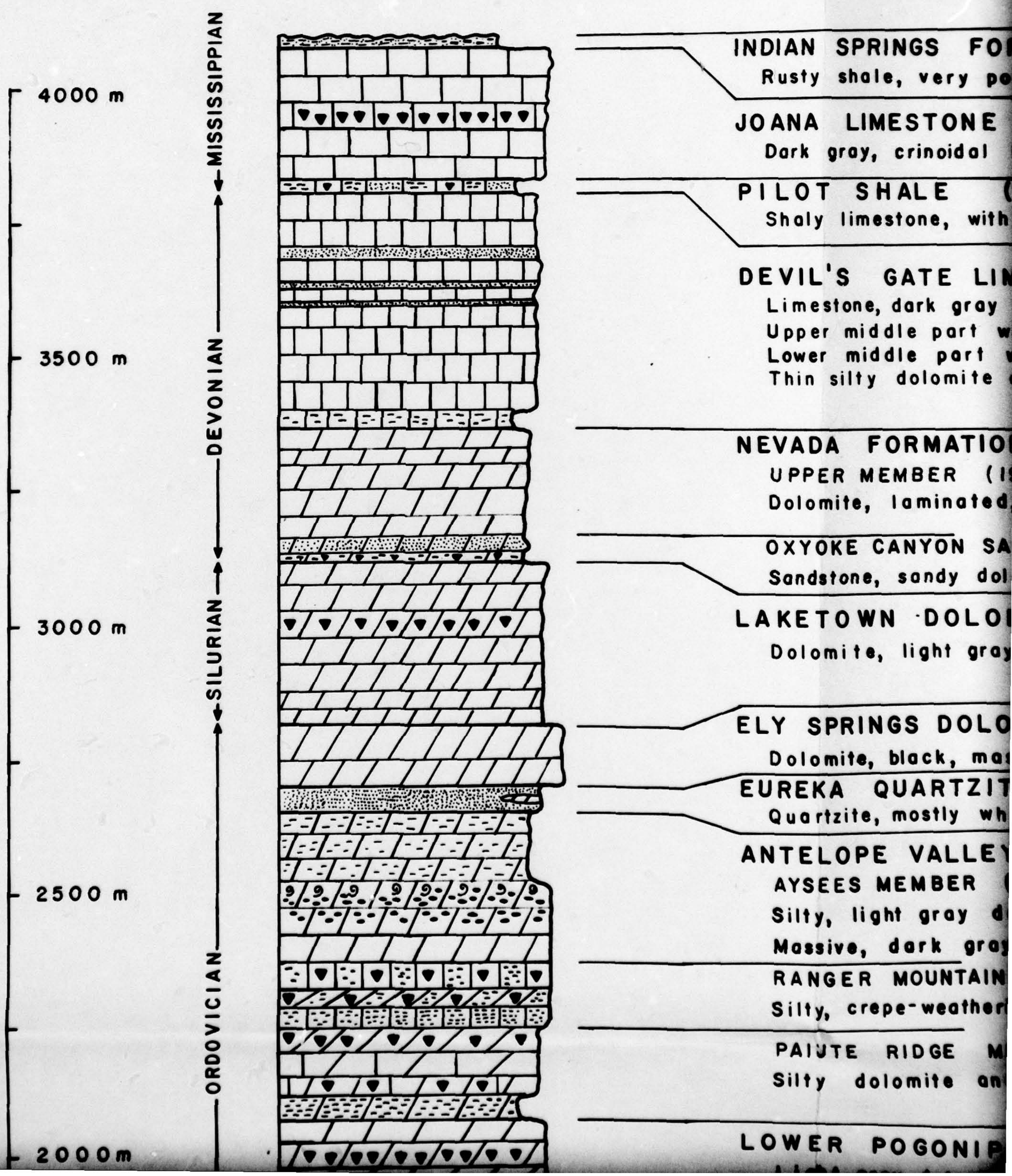

B'
D'
E'
Gass Peak Thrust
Qal
Cbp
Cc
Cwc
PPbs
Hidden Valley
115° 5'
115° 2' 30"
115°

Plate 3. Stratigraphic Column, Sheep Range



2

umn, Sheep Range

INDIAN SPRINGS FORMATION (30 m)
Rusty shale, very poorly exposed

JOANA LIMESTONE (250 m)
Dark gray, crinoidal limestone, with prominent cherty zone

PILOT SHALE (15 m)
Shaly limestone, with thin basal quartzite and bedded chert

DEVIL'S GATE LIMESTONE (440 m)
Limestone, dark gray to blue gray
Upper middle part with interbedded clean quartzite
Lower middle part with abundant stromatoporoids
Thin silty dolomite at base

NEVADA FORMATION (245 m)
UPPER MEMBER (195 m)
Dolomite, laminated, dark to light gray

OXYOKE CANYON SANDSTONE-BEACON PEAK DOLOMITE (50m)
Sandstone, sandy dolomite, cherty dolomite, and silty dolomite

LAKETOWN DOLOMITE (300 m)
Dolomite, light gray, thin bedded, some chert

ELY SPRINGS DOLOMITE (140 m)
Dolomite, black, massive

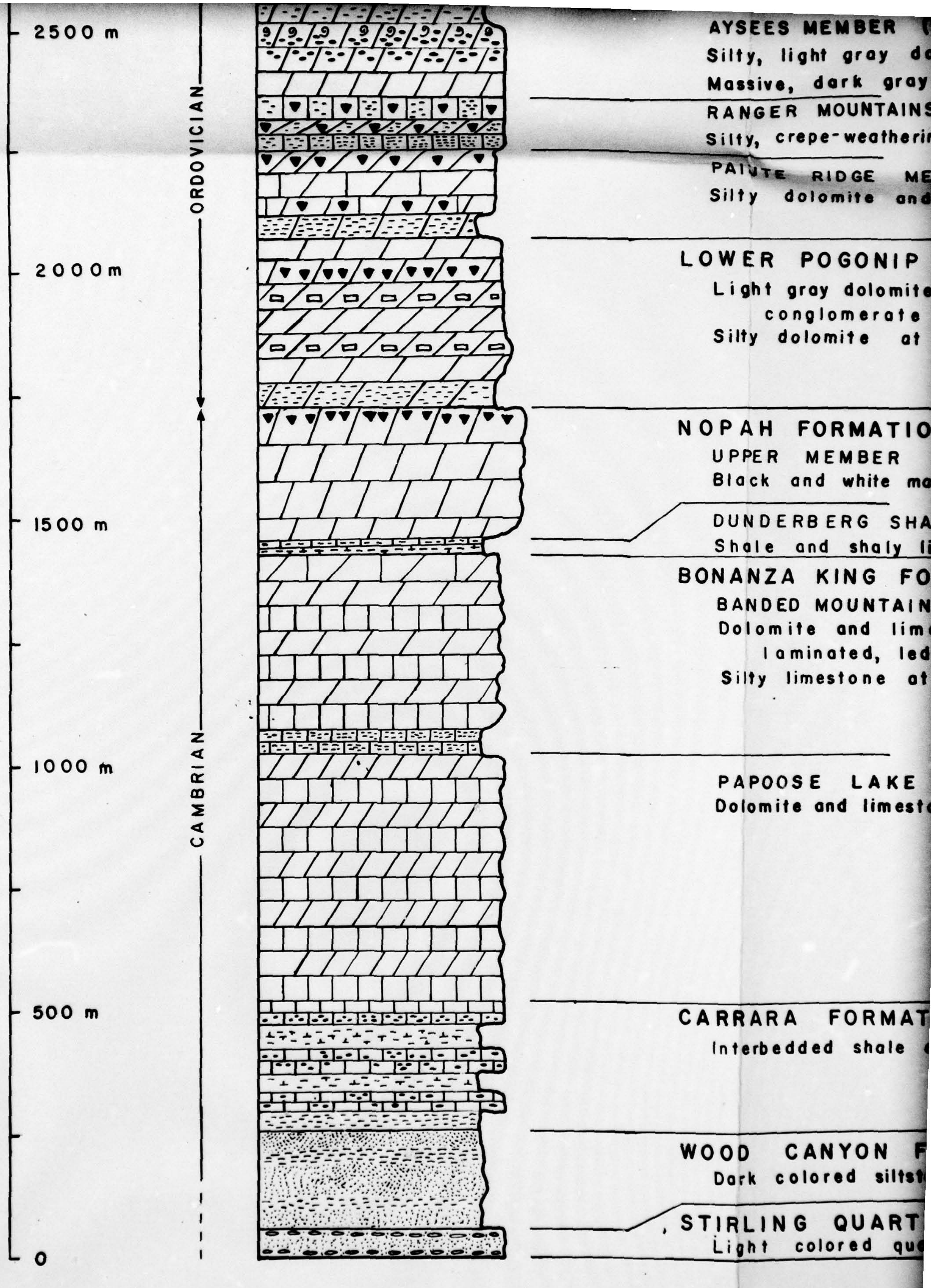
EUREKA QUARTZITE (50 m)
Quartzite, mostly white and vitreous, minor dolomite

ANTELOPE VALLEY LIMESTONE (586 m)
AYSEES MEMBER (278 m)
Silty, light gray dolomite in upper part
Massive, dark gray dolomite in lower part

RANGER MOUNTAINS MEMBER (128 m)
Silty, crepe-weathering limestone and dolomite

PAIUTE RIDGE MEMBER (180 m)
Silty dolomite and minor limestone

LOWER POGONIP GROUP UNDIFFERENTIATED (324m)
Light gray dolomite, cherty, with intraformational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Massive, dark gray
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Silty, crepe-weatherin
RIDGE ME
Silty dolomite and
LOWER POGONIP
Light gray dolomite,
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Silty dolomite at
NOPAH FORMATIO
UPPER MEMBER
Black and white ma
DUNDERBERG SHA
Shale and shaly li
BONANZA KING FO
BANDED MOUNTAIN
Dolomite and lime
laminated, led
Silty limestone at
PAPOOSE LAKE
Dolomite and limest
CARRARA FORMAT
Interbedded shale
WOOD CANYON F
Dark colored silts
STIRLING QUART
Light colored qu

AYSEES MEMBER (278 m)
Silty, light gray dolomite in upper part
Massive, dark gray dolomite in lower part

RANGER MOUNTAINS MEMBER (128 m)
Silty, crepe-weathering limestone and dolomite

PAIUTE RIDGE MEMBER (180 m)
Silty dolomite and minor limestone

LOWER POGONIP GROUP UNDIFFERENTIATED (324m)
Light gray dolomite, cherty, with intraformational conglomerate
Silty dolomite at base

NOPAH FORMATION (300m)
UPPER MEMBER (270 m)
Black and white massive dolomite

DUNDERBERG SHALE (30 m)
Shale and shaly limestone

BONANZA KING FORMATION (900 m)
BANDED MOUNTAIN MEMBER (410 m)
Dolomite and limestone, color-banded, mottled, laminated, ledge-forming
Silty limestone at base

PAPOOSE LAKE MEMBER (490 m)
Dolomite and limestone, mottled, burrowed, laminated

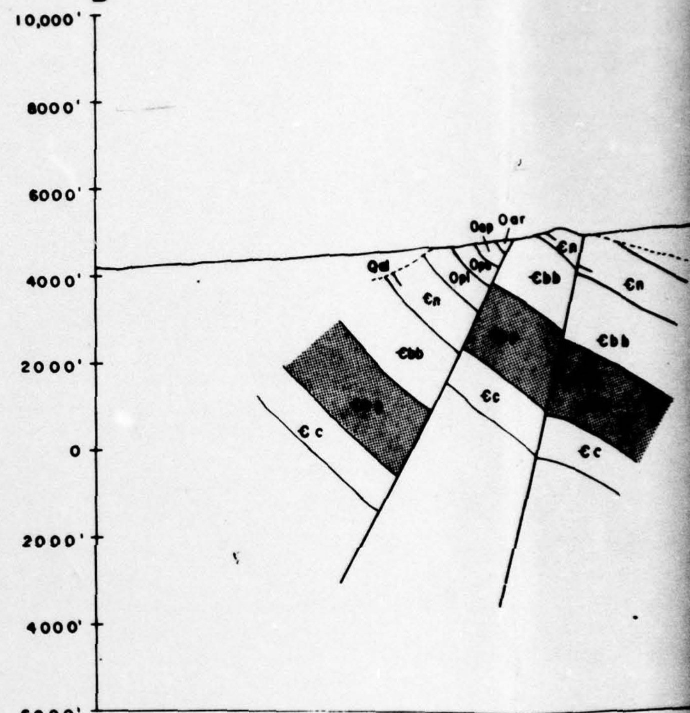
CARRARA FORMATION (265 m)
Interbedded shale and limestone

WOOD CANYON FORMATION (200 m)
Dark colored siltstone and quartzite

STIRLING QUARTZITE (60 m)
Light colored quartzite and conglomerate

Plate 2. Cross s

B



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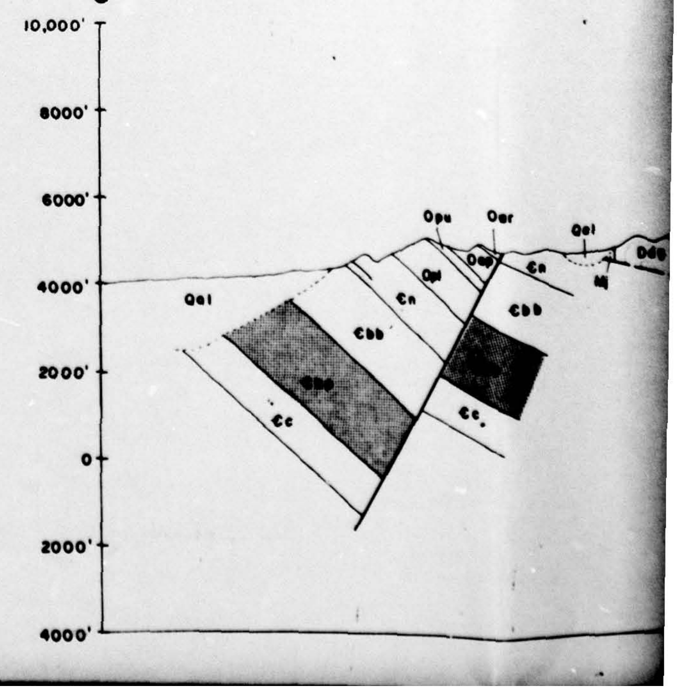

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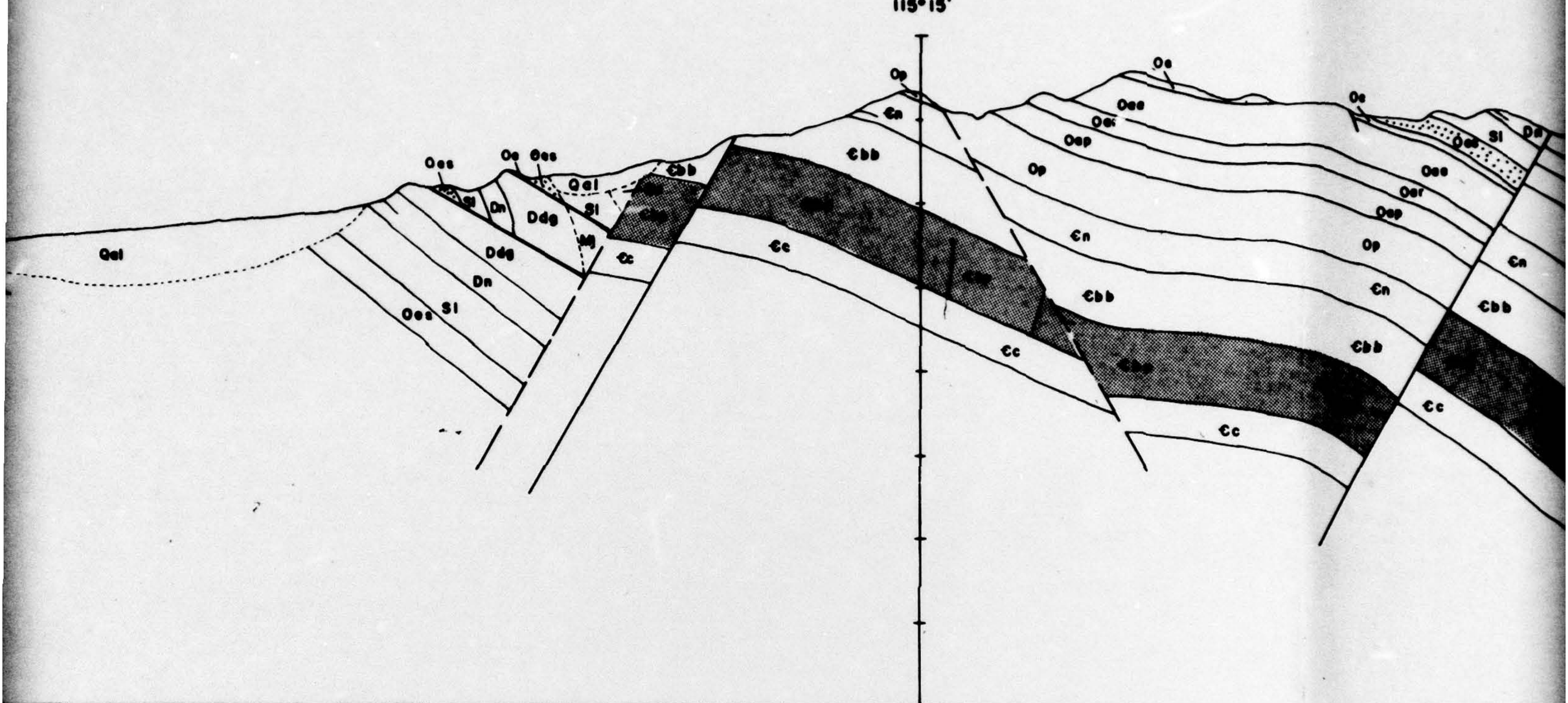

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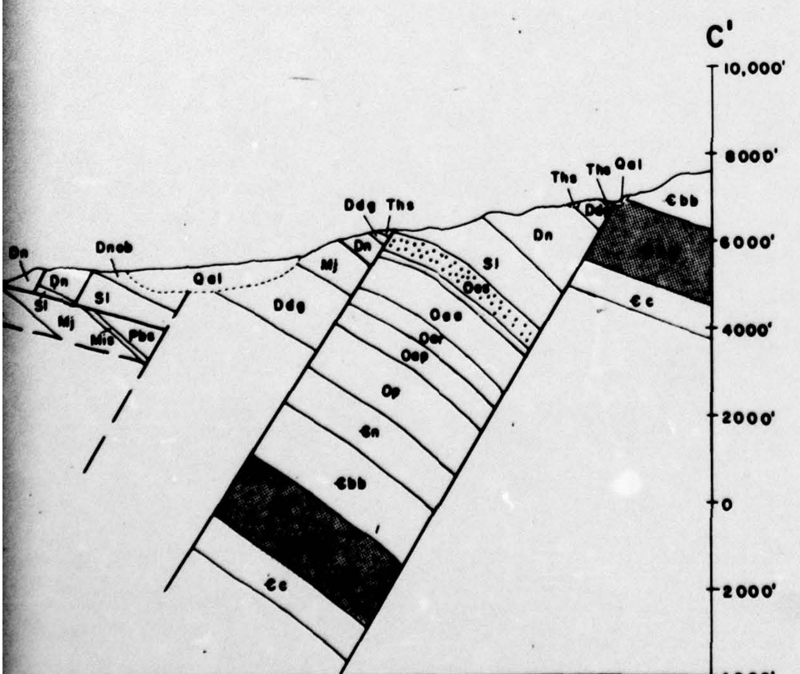

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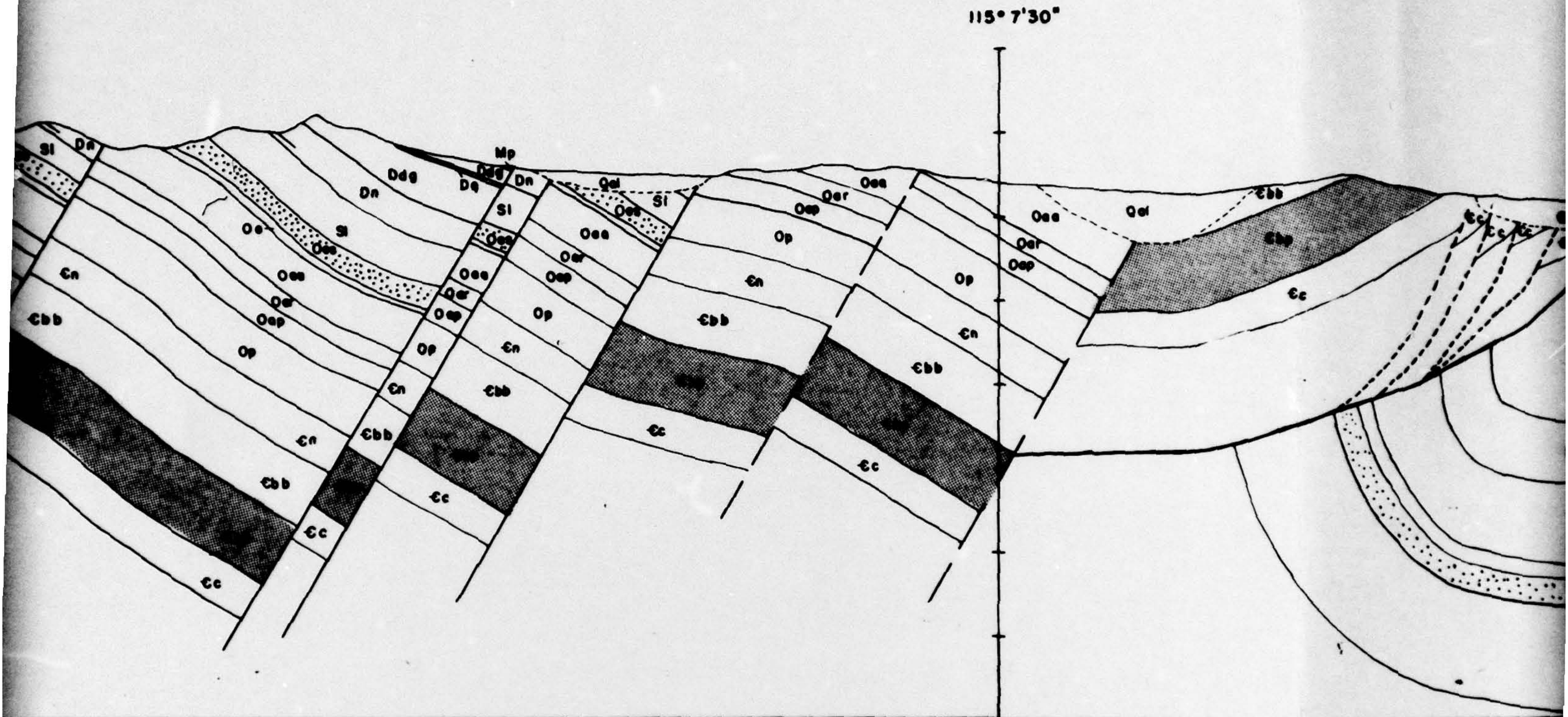
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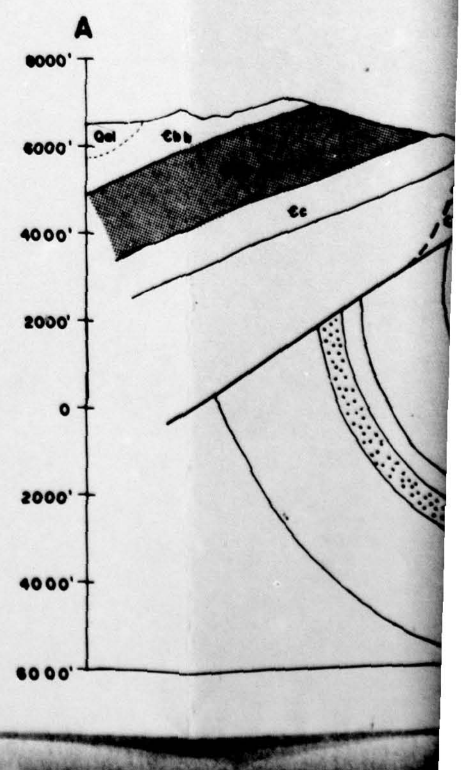
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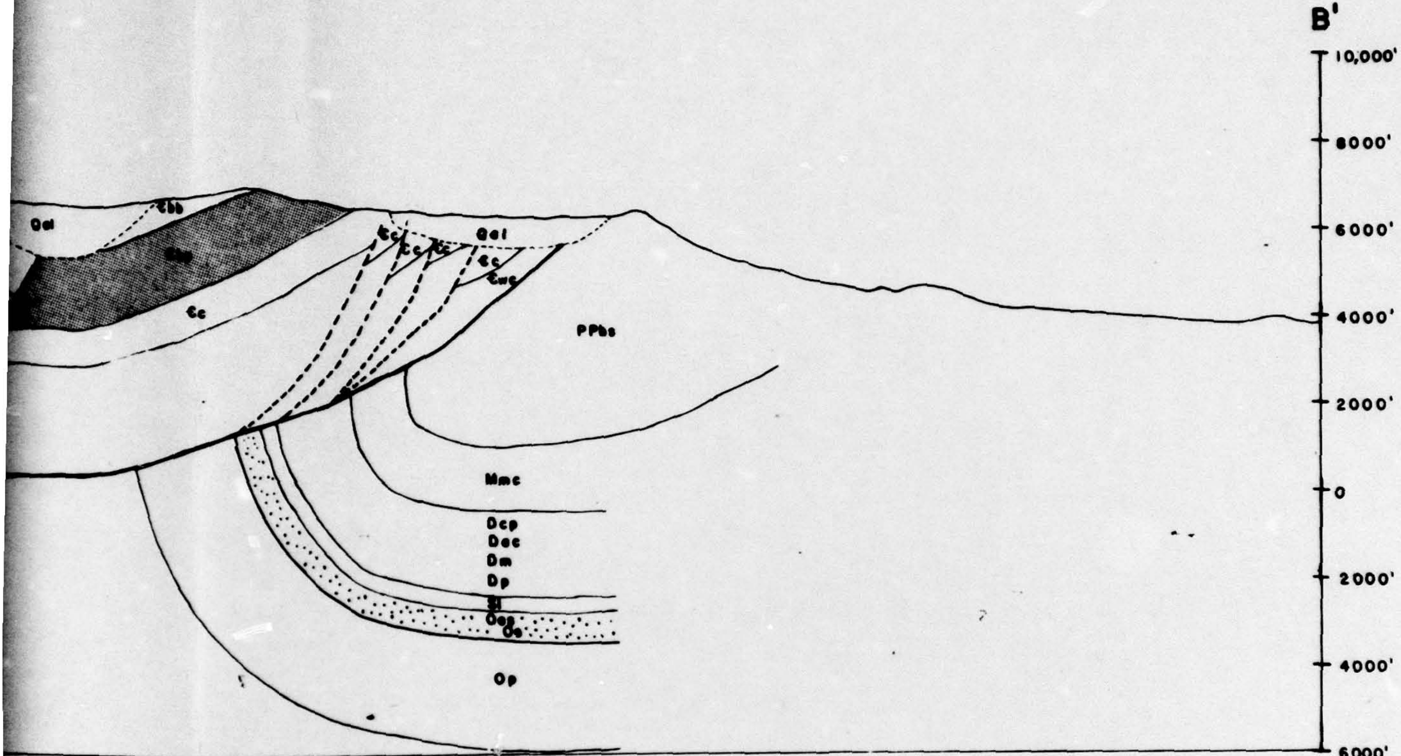
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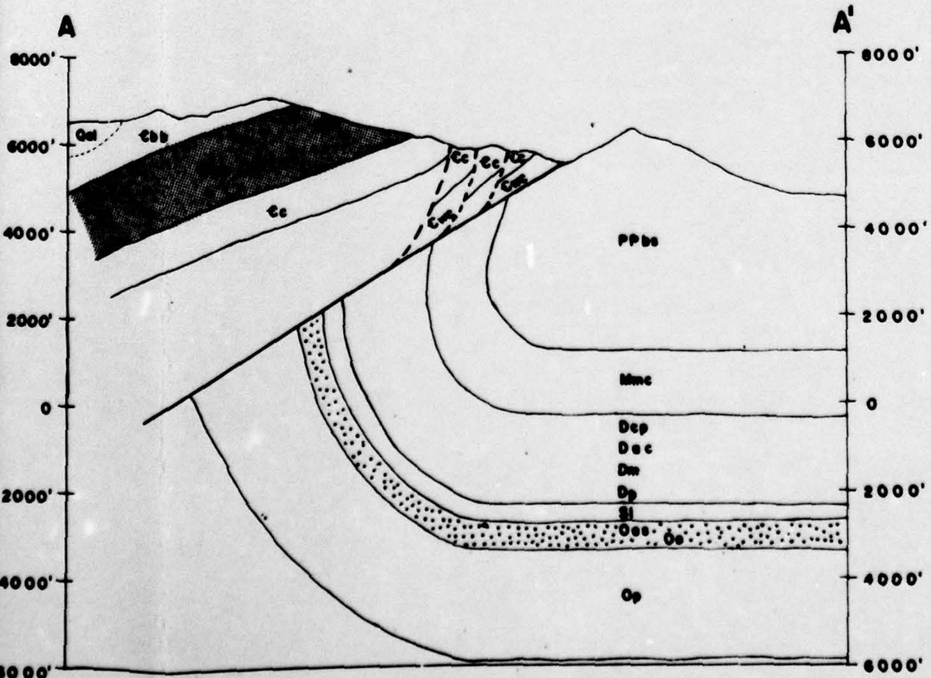
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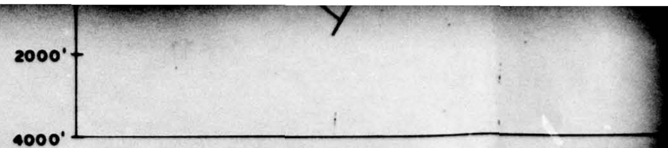

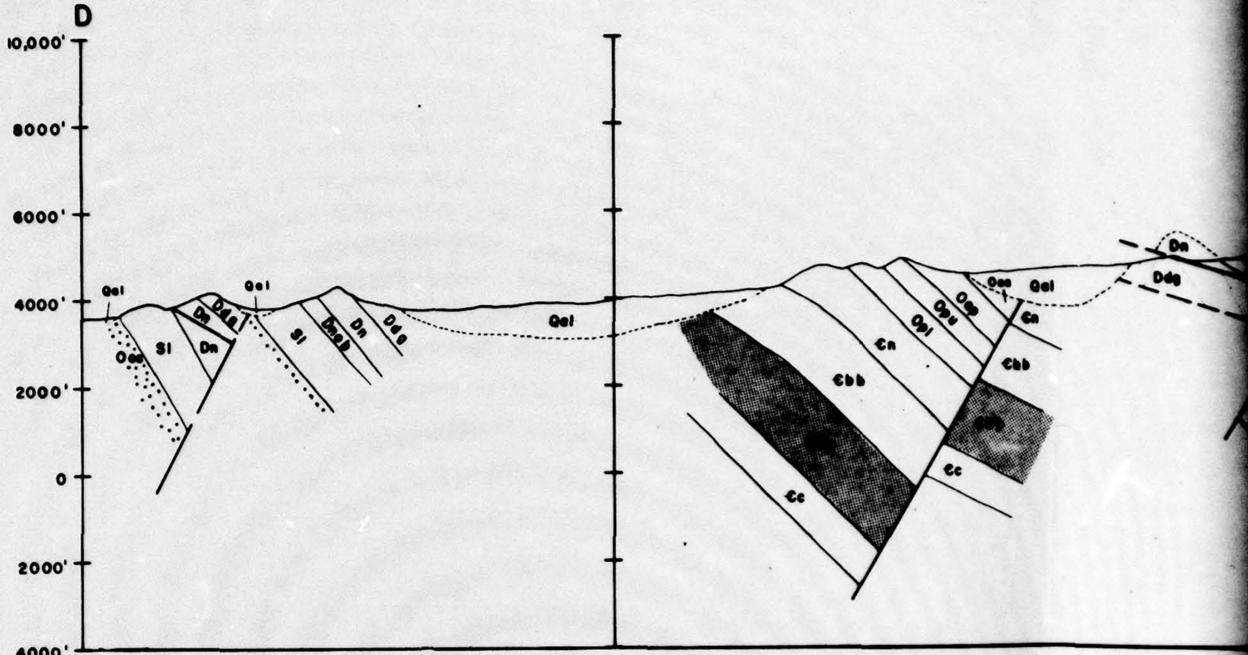

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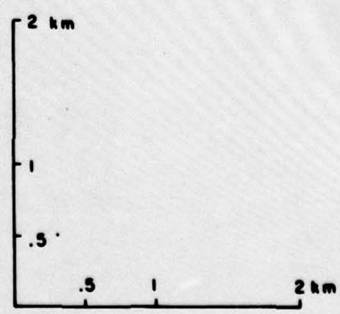

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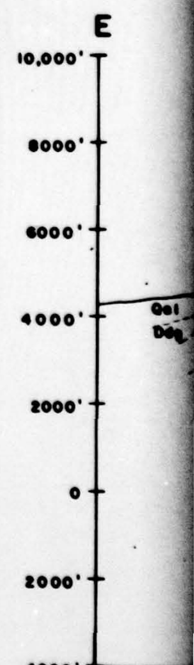

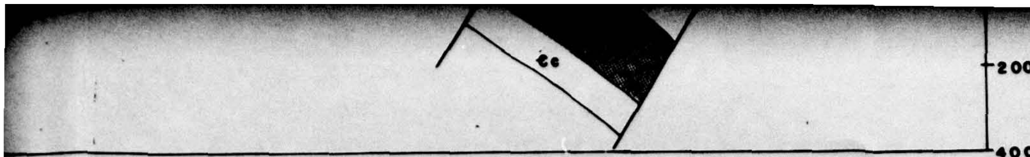
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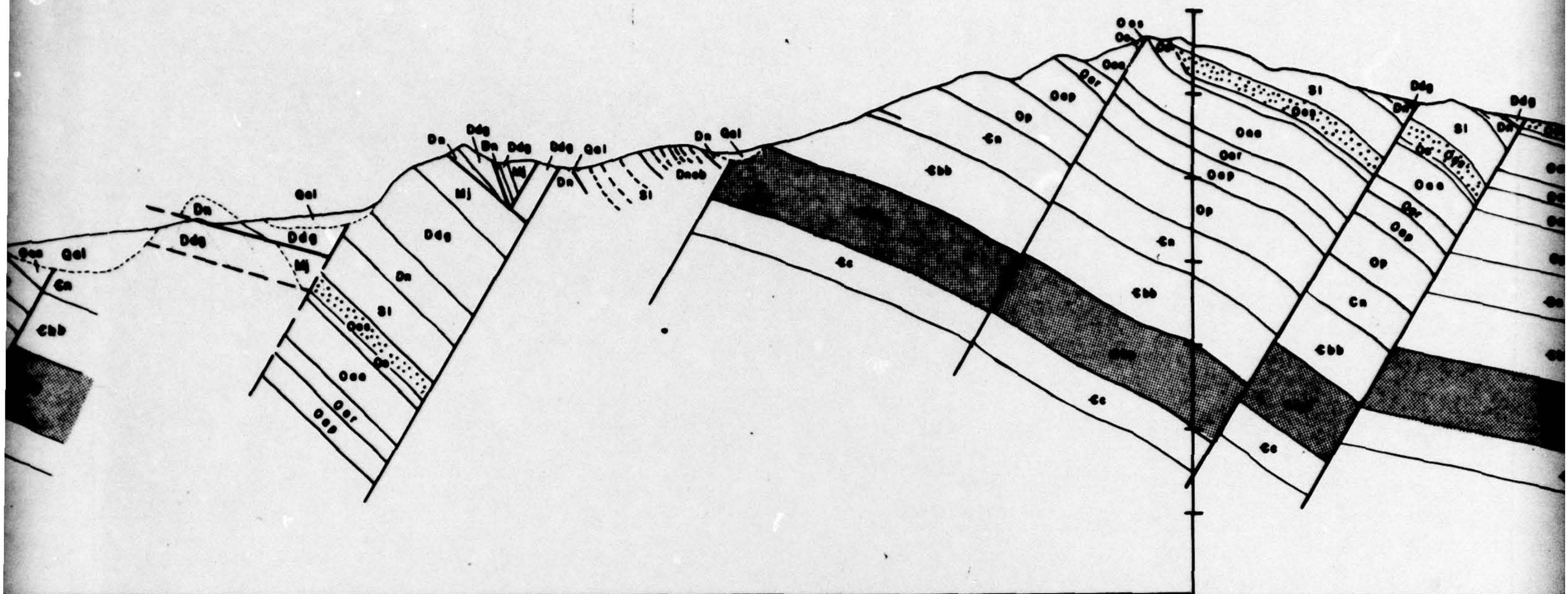
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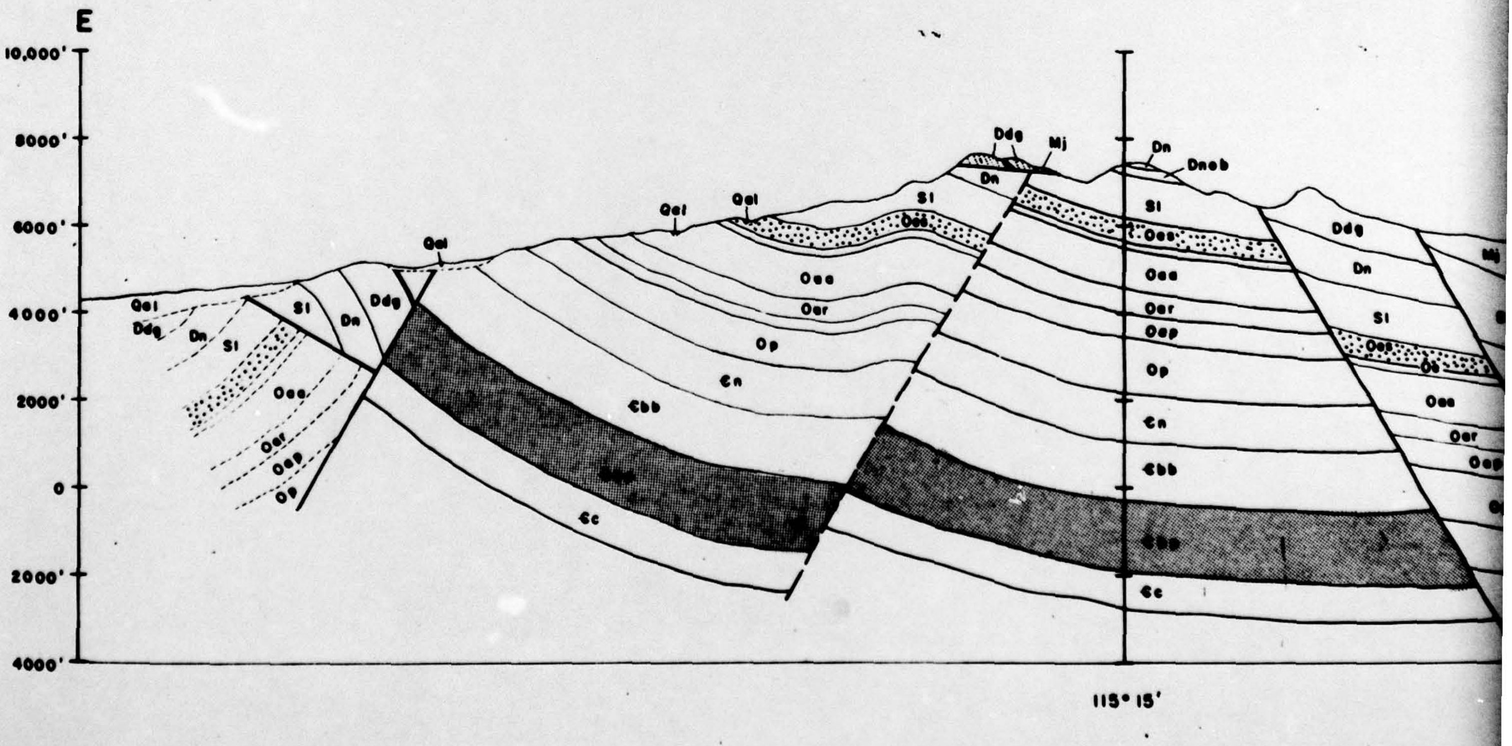
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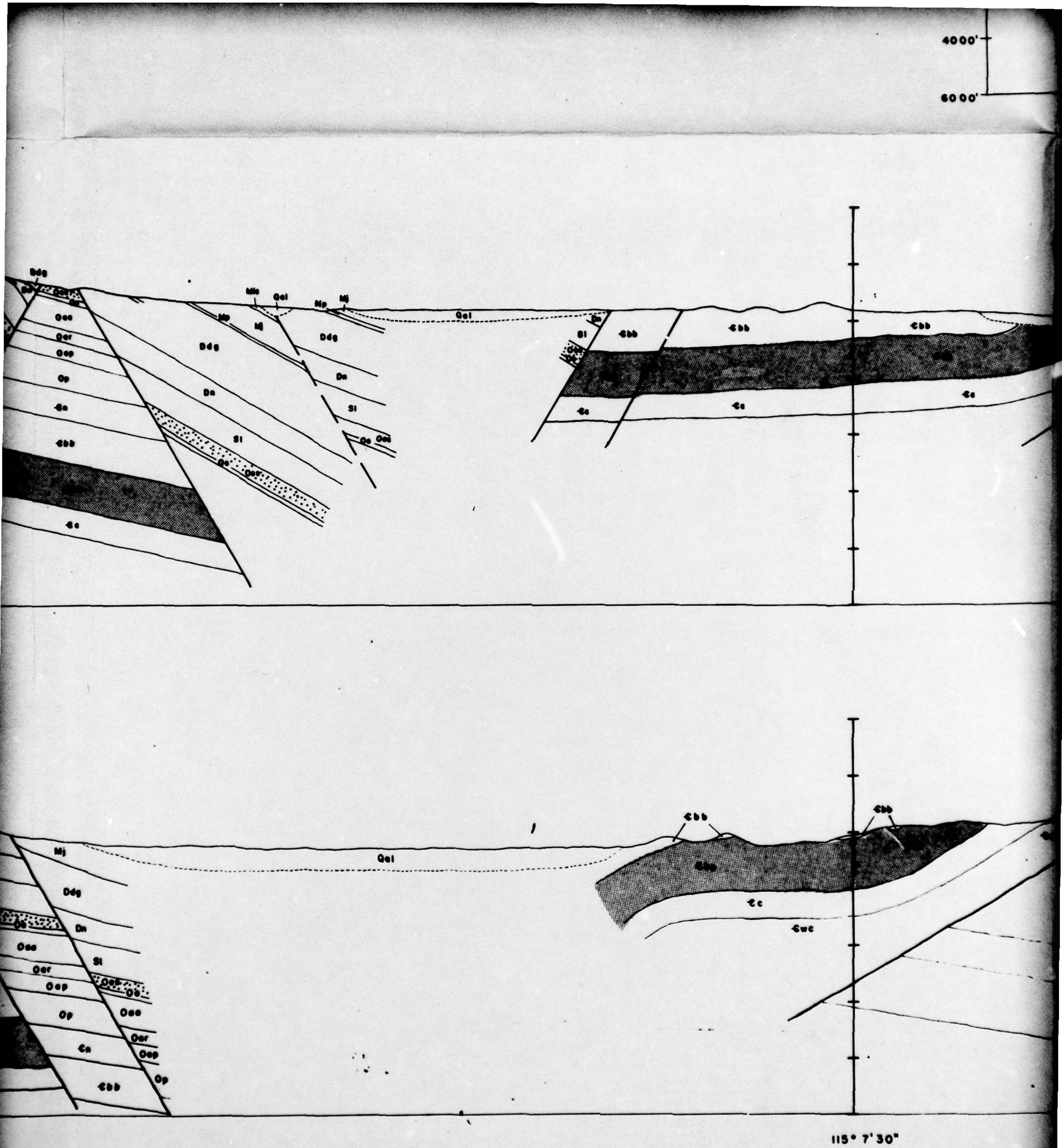

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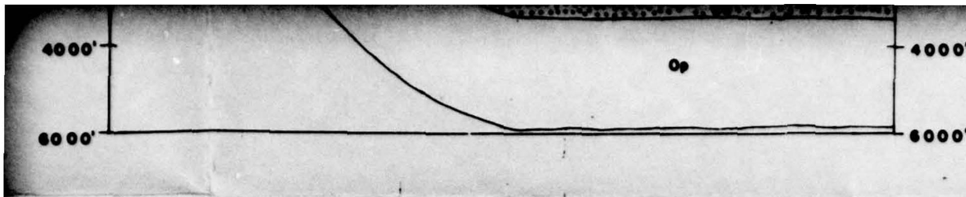
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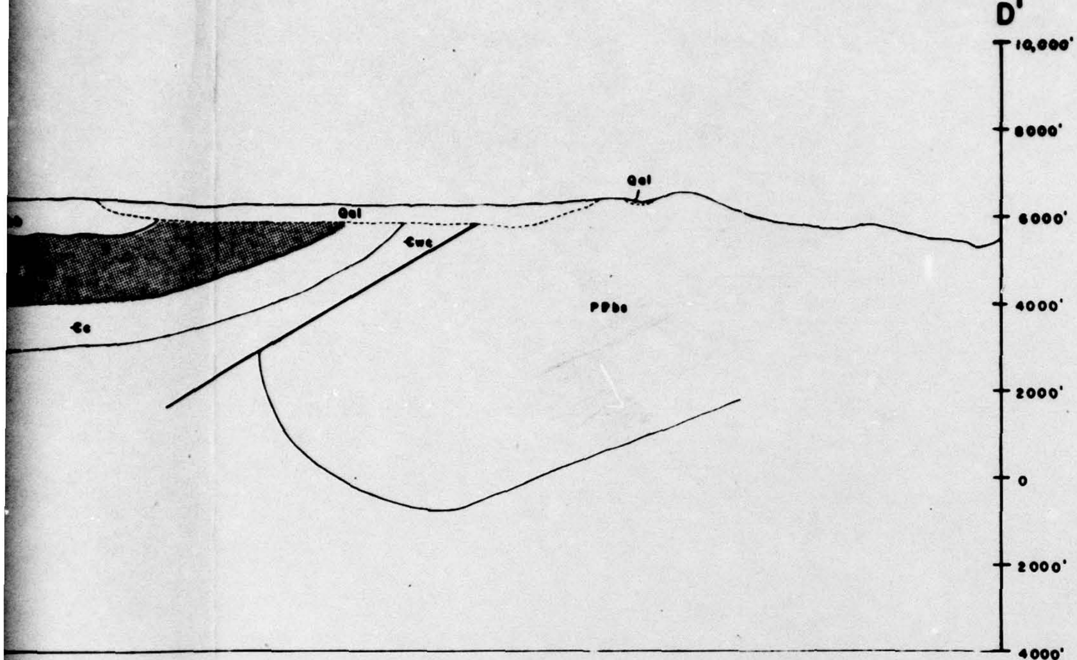
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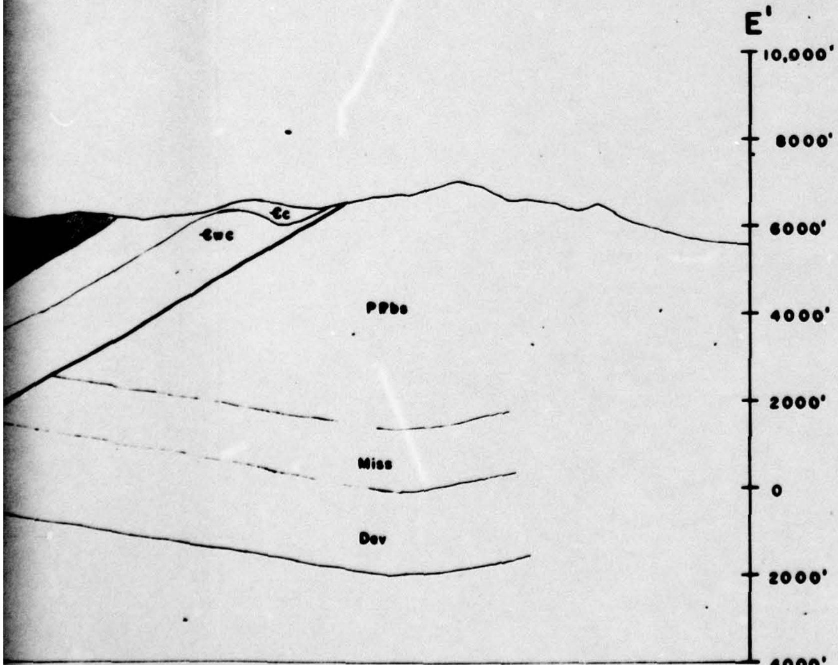
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